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THE DESIGN OF AXIAL COMPRESSOR AIRF L3  
USING ARBITRARY CHAMBER LINES

George R. Frost, et al

Aerospace Research Laboratories  
Wright-Patterson Air Force Base, Ohio

July 1973

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## Aerospace Research Laboratories

### THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CAMBER LINES

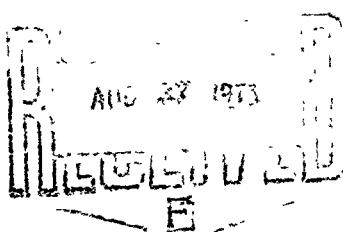
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FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

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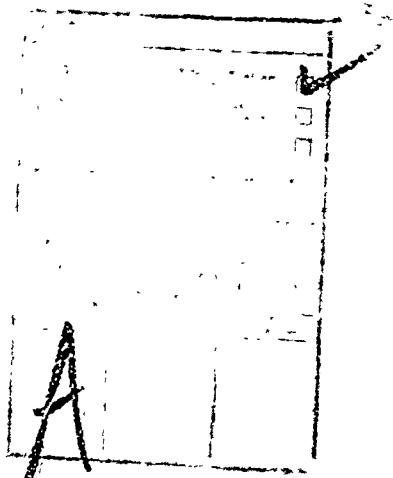
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# THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CAMBER LINES

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JULY 1973

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AIR FORCE SYSTEMS COMMAND  
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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## FOREWORD

This report was prepared by Captain George R. Frost and Dr. Arthur J. Wennerstrom of the Fluid Dynamics Facilities Research Laboratory, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio.

The report presents results from a portion of the effort of the Fluid Machinery Research Group supervised by Dr. Arthur J. Wennerstrom and was conducted under Work Unit 09 of Project 7065, "Aerospace Simulation Techniques Research" under the overall direction of Mr. Elmer G. Johnson.

## ABSTRACT

This report describes a technique which has been developed for use in the design of axial compressor airfoils with camber lines of arbitrary shape. The slope of the camber line at several points on a streamsurface is determined from the air angles at these points as well as the incidence and deviation angle distributions for the blade. A camber line is produced by fitting a smooth curve segment through each pair of points from the leading to the trailing edge. A thickness distribution is applied to this camber line to produce the blade element. A computer program which uses this technique to produce blade elements, stack them, and then determine coordinates for plane surfaces through the resultant blade is also described.

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## SECTION I

### INTRODUCTION

The traditional approach to the selection of blades for axial-flow compressors has been to choose a specific type of airfoil, subsequently to adjust the parameters defining that airfoil to suit prevailing aerodynamic conditions. Many successful designs have been accomplished in this manner using such blades as NACA 65-series, double circular arc, multiple circular arc, etc. This approach has the virtue of employing airfoil sections about which something is usually known with respect to losses, deviation angle, and operating limits. Reference 1, an earlier publication of this laboratory, is representative of this approach.

A typical contemporary design will be accomplished using a streamline curvature or matrix through-flow analysis incorporating computing stations internal to blade rows as well as at blade edges and in free spaces. Some criterion for optimization of blade shape must be chosen. (The authors of this report choose to achieve a particular shape of static pressure distribution along streamlines.) The spanwise distributions of inlet and outlet relative flow angles, loss coefficients, etc. will have been determined through some preliminary design procedure. A rule for determining deviation angle and distributing it along streamlines will have been selected. Subsequently, the aerodynamic blade design procedure consists of assuming a blade geometry, performing an aerodynamic analysis using specified relative flow angles as input data, and then repeating this procedure as many times as necessary, varying the parameters describing the airfoil sections, until the result of the aerodynamic analysis adequately satisfies the chosen optimization criterion.

There are three principal disadvantages to employing this procedure for the design of transonic and supersonic blade rows. First, the iteration required is time consuming and, to some degree, laborious. Many adjustments to the geometry specified may be required before optimization objectives are met. Although the bulk of the calculations are performed by computer, the designer generally must still examine and evaluate the aerodynamic result and decide what to change, and how much, for the next attempt. Second, when airfoil shape is restricted to any particular class of airfoil, it will rarely be possible to achieve the optimization objectives as closely as might be desired, everywhere along the span. Some compromise will nearly always be necessary. Third, streamline curvature and matrix through-flow analyses sometimes experience difficulty in finding solutions for certain combinations of high relative Mach number and high absolute Mach number near choking when relative flow

angle is specified as input data within blade rows. This is a numerical problem related to the construction of these computer programs and can vary considerably from one program to another.

A design method which eliminates or appreciably reduces these problems consists of specifying total temperature (in rotors) or the product of radius and whirl velocity (in stators) as input data to the aerodynamic analysis program and then fitting airfoils of arbitrary shape to the resulting relative flow angles. In so doing, one loses the data base which might be associated with a particular class of airfoil, but the value of such a geometrically-related data base is questionable for transonic and supersonic sections. Following this approach, the aerodynamic analysis can be optimized with considerably fewer iterations than are usually required with specified geometry. In most cases, optimization objectives can be achieved on nearly every streamsurface. Some interaction is required between the blade design program and the aerodynamic analysis to insure that the blade lean angles and blockages are kept up-to-date. However, the over-all effort required to achieve a satisfactory design using this method has been found to be substantially less.

The principal difficulty in developing a procedure to define arbitrary airfoils consists of arriving at a method which produces aerodynamically attractive shapes which are in addition practical from a structural and manufacturing viewpoint. This report describes one such method developed at the Aerospace Research Laboratories. The method has been incorporated into a computer program which is an extension of the work reported in Reference 1. In addition to determining the shape of the airfoils on aerodynamic surfaces, section properties are computed, the blade is stacked, and Cartesian coordinates are determined for manufacturing purposes.

The overall design technique is described in Section II. The mathematical details of implementing the technique in a calculation procedure are described in Sections III and IV. A method of producing the optimal camber line on a streamsurface is treated in Section III; the calculations related to other aspects of the blade design procedure are discussed briefly in Section IV. Sections V, VI, and VII present the details of and use of a computer program which incorporates this design technique, currently used at the Aerospace Research Laboratories in the design of axial compressor airfoils.

## SECTION II

### DESCRIPTION OF THE TECHNIQUE

#### 1. TECHNIQUE OVERVIEW

The technique described in this report uses an iterative procedure to produce an "optimal" camber line on each stream-surface. A thickness distribution is applied to each camber line, and the resulting blade elements are stacked to produce the desired airfoil. The technique requires the designer to specify the incidence distribution radially at the blade leading edge, the location of the stack axis and the stacking offsets of each streamsurface section centroid therefrom, the parameters of the thickness distribution, and the chordwise distribution of deviation angle along the span.

The optimization criterion which has been selected for the section camber line is to maximize the absolute value of the minimum radius of curvature on the camber line. The "optimal" camber line is chosen from a set of camber lines containing the minimum number of inflection points. This original set of camber lines is generated by varying the second derivative at the leading edge.

The starting point of the design technique is output data from an aerodynamic analysis of a particular blade row which has been generated by specifying a parameter other than blade geometry, such as those suggested in the Introduction, across the blade row. This data is in the form of the meridional coordinates of the streamsurfaces and the chordwise distribution of the relative air angles on each streamsurface. The essential steps of the technique itself are described in a qualitative sense in the remainder of this section.

#### 2. DETAILS OF THE TECHNIQUE

The first step of the overall procedure is to determine the optimal blade section on each streamsurface. This in itself is a multiple-step process which incorporates an iteration with solidity to establish a camber line for each of a range of values of the second derivative at the leading edge, a search procedure to choose the "optimal" camber line, and the application of a thickness distribution to this camber line.

The procedure begins with an initial estimate of solidity on the streamsurface. This estimate is made by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord length, obtained by integrating along each streamline from the assumed

leading to trailing edge, to get a first estimate of the true chord. The solidity is then computed from this estimate, the mean streamsurface radius, and the number of blades in the blade row.

The total deviation angle is computed from this estimate in some fashion, such as the modified Carter's Rule with appropriate constants. The deviation angle at each internal point is next determined as a designer-specified fraction of the total deviation. The required section angle at each internal point and at the trailing edge is then the difference between the relative air angle and the deviation angle, while the section angle at the leading edge is the difference between the relative air angle and the incidence angle.

Each section camber line is determined by fitting a segment of a smooth curve, such as a cubic, between each pair of points from the leading to the trailing edge of the section. The slope at the endpoint of each segment matches the specified section angle there. The true chord length and the associated value of solidity can then be determined. If the solidity differs by more than a prescribed tolerance from the previous estimate, the steps subsequent to and including the total deviation determination are repeated for the revised values of solidity until the desired tolerance is achieved.

The entire procedure described thus far is repeated for a range of values of the second derivative at the leading edge. The resultant set of camber lines are inspected first to focus only on those which contain the minimum number of inflection points, and from these to choose the camber line which is "optimal" in the sense previously described.

A thickness distribution is then applied to this camber line, and the procedure is repeated for each streamsurface. The blade sections are stacked, and the Cartesian coordinates of the resulting blade determined. In addition, the blade blockage and lean angle are computed at each appropriate streamsurface-computing station intersection point.

As a final step, the designer inspects the resulting blockages, Cartesian centroid offsets, blade lean angles, and coincidence of the blade edges with the designated computing stations. If necessary, appropriate changes are made in the inputs to the aerodynamic analysis, and the entire procedure recycled until adequate overall coincidence between the blade design and the aerodynamic analysis is achieved.

### SECTION III

#### THE SECTION CAMBER LINE

The first item required in the application of the technique described in the preceding section is the meridional chord length of the blade element, obtained by integrating along the streamline between the assumed leading and trailing edges. This is accomplished by passing a spline curve through the meridional coordinates ( $x, r$ ) of the streamsurface. The slope of the streamsurface is calculated (as the slope of the spline-curve) at 100 points distributed uniformly on the  $x$ -axis (axially) between the edges of the blade section. The chord length,  $C_m$ , is obtained from the equation

$$C_m = \sum_{n=2}^{100} (x_n - x_{n-1}) \sqrt{1 + \left[ \left( \frac{dr}{dx_n} + \frac{dr}{dx_{n-1}} \right) / 2 \right]^2} \quad (1)$$

An estimate of true chord is obtained by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord so that the true chord estimate,  $C_e$ , is

$$C_e = \frac{C_m}{\cos \left( \frac{\beta_{le} + \beta_{te}}{2} \right)} \quad (2)$$

The first estimate of solidity may be computed from the equation

$$\sigma = \frac{NC_e}{2\pi \left( \frac{r_{le} + r_{te}}{2} \right)} \quad (3)$$

where  $N$  is the number of blades and  $r_{le}$ ,  $r_{te}$  are the radii of the streamsurface at the leading and trailing edges, respectively.

The calculation of the deviation angle,  $\delta$ , follows the NASA method (Reference 2, Equations 269 and 271) with an additional term,  $\gamma$ .

$$\delta = \delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{le} - i - \beta_{te} + \delta) + \gamma \quad (4)$$

where  $\delta_{0_{10}}$  is the variation from the reference deviation for a 10 percent-thick NACA 65-series thickness distribution

$K_{\delta_s}$  is a correction factor for a blade shape with a thickness distribution different from a 65-series blade

$K_{\delta_t}$  is a correction factor for a maximum thickness other than 10 percent

$m$  is the slope of the deviation angle variation from reference deviation with camber

$b$  is the solidity exponent (variable with air inlet angle)

$\beta_{xe}$  is the relative air angle at the particular edge

$i$  is the incidence angle

$\gamma$  is the arbitrary extra deviation

Solving Eq (4) for  $\delta$  yields

$$\delta = \frac{\delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{le} - i - \beta_{te}) + \gamma}{(1 - \frac{m}{\sigma^b})} \quad (5)$$

For use in the calculation procedure,  $K_{\delta_s}$ ,  $i$ , and  $\gamma$  are specified by the designer. Several of the other quantities are obtained from known quantities and figures of Reference 2:  $\delta_{0_{10}}$  from Figure 161;  $K_{\delta_t}$ , Figure 172;  $m$ , Figure 166; and  $b$ , Figure 164.

The blade angle,  $\alpha$ , is established at several points across the blade element from the relative air angle,  $\beta$ , modified by the proper consideration of incidence or deviation. At the leading edge,

$$\alpha_{le} = \beta_{le} - i \quad (6)$$

and at the trailing edge,

$$\alpha_{te} = \beta_{te} - \delta \quad (7)$$

At the other points, the blade angles are determined by subtracting a fraction  $f$  of the trailing-edge deviation from the relative air angle. At each internal point  $j$ ,

$$\alpha_j = \beta_j - f_j \delta \quad (8)$$

The fraction  $f_j$  is determined by radial interpolation from the deviation distributions specified by the designer.

The camber line is constructed by fitting a third order polynomial (cubic) through each pair of points from the leading to the trailing edge of the section. Thus, each segment of the camber line is defined by equations of the form

$$y = ax^3 + bx^2 + cx + d \quad (9)$$

$$y' = 3ax^2 + 2bx + c \quad (10)$$

$$y'' = 6ax + 2b \quad (11)$$

As a result, each segment has at most one inflection point ( $y'' = 0$ ) in its useful range, and in most instances has none.

The constants  $a$ ,  $b$ ,  $c$ , and  $d$  for any particular segment can be expressed in terms of the endpoints (denoted by subscripts 1 and 2) of that segment as

$$a = \frac{(y_2' - y_1') - y_1''(x_2 - x_1)}{3[(x_2^2 - x_1^2) - 2x_1(x_2 - x_1)]} \quad (12)$$

$$b = \frac{y_1'' - 6ax_1}{2} \quad (13)$$

$$c = y_1' - 3ax_1^2 - 2bx_1 \quad (14)$$

$$d = y_1 - ax_1^3 - bx_1^2 - cx_1 \quad (15)$$

For simplicity, the leading edge of the camber line is placed at the origin of the coordinate system, resulting in the following boundary conditions for the first segment:

At  $x = 0$ ,  $y = 0$

$$y' = \tan \alpha_{le} \quad (16)$$

$$y'' = y_o''$$

$$\text{At } x = x_1, y' = \tan \alpha_1 \quad (17)$$

With these boundary conditions, the appropriate values of  $a$ ,  $b$ ,  $c$ , and  $d$  for this segment are completely determined.

The boundary conditions for the second and subsequent segments are specified at one endpoint by equating the first and second derivatives to the values for the preceding segment at the point of juncture; for example, for the second segment,

At  $x = x_1$ ,  $y = y_1$  (first segment)

$$y' = \tan \alpha_1 \quad (18)$$

$$y'' = y_1'' \text{ (first segment)}$$

and at the other endpoint,

$$\text{At } x = x_2, y' = \tan \alpha_2 \quad (19)$$

From these conditions, a distinct set of constants ( $a$ ,  $b$ ,  $c$ ,  $d$ ) are computed for the second segment. This same procedure is applied to each pair of points to produce a camber line with continuous first and second derivatives all along its length.

Note that the first segment of the camber line requires the specification of the second derivative  $y_o''$  at the leading edge. This boundary condition affects the constants of the first segment and thus the nature of this entire segment, including the conditions  $(y_1, y_1'')$  at the other endpoint. Since the constants for the second segment are established from these conditions, and so on for the rest of the segments, the nature of the entire camber line depends on the value of  $y_o''$  specified at the leading edge.

It has been found convenient to specify  $y_o''$  in terms of a non-dimensional parameter  $S/R_o$ , the ratio of blade spacing,  $S$ , to the radius of curvature,  $R_o$ , at the leading edge.  $R_o$  is given by the equation

$$R_o = \frac{\left[1 + \tan^2 \alpha_{le}\right]^{3/2}}{y_o''} \quad (20)$$

and  $S$  is obtained from

$$S = \frac{2\pi r_{le}}{N} \quad (21)$$

From Equations (20) and (21),

$$\frac{S}{R_o} = \frac{2\pi r_{le} y_o''}{N \left[1 + \tan^2 \alpha_{le}\right]^{3/2}} \quad (22)$$

Solving for  $y_o''$  gives

$$y_o'' = \frac{N \left[ 1 + \tan^2 \alpha_{le} \right]^{3/2}}{2\pi r_{le}} \cdot \frac{S}{R_o} \quad (23)$$

which indicates that  $y_o''$  is the parameter  $S/R_o$  multiplied by a constant.

For a particular value of  $S/R_o$ , the true chord length of the resulting camber lines may be determined from the endpoint of the final segment as

$$C = \sqrt{(x_{te})^2 + (y_{te})^2} \quad (24)$$

This value is used to compute a revised value of solidity, which is compared to the original estimate. If satisfactory coincidence has not been achieved, a corrected deviation angle is computed from the revised solidity, and the camber line reconstructed. This iteration is repeated until adequate coincidence has been obtained.

It is difficult if not impossible to have an intuitive notion of a "good" value of  $y_o''$  (hence,  $S/R_o$ ). For some ranges of  $S/R_o$ , each camber line segment may contain an inflection point, while for other ranges, few if any segments may contain such a point. The authors of this report have assumed that, for aerodynamic as well as mechanical reasons, the most desirable airfoil among several matching the same flow angle at each computing station will be one having the minimum number of inflection points between leading and trailing edge. This is accomplished by calculating the camber line for a broad range of values of  $S/R_o$  and isolating the range in which the minimum total number of inflection points occurs. This range is examined with finer  $S/R_o$  increments to generate a new set of camber lines on which the minimum absolute radius of curvature is identified. The value of  $S/R_o$  which produces the largest such radius is then made the mid-value of  $S/R_o$  for the final search pass, using still finer  $S/R_o$  increments. The camber line which possesses the largest value of the minimum radius of curvature at the conclusion of this search procedure is chosen as opt.

## SECTION I'

### OTHER ASPECTS OF THE CALCULATION PROCEDURE

Various other aspects of the calculation procedure are discussed briefly in this section. For greater detail on these topics, the reader's attention is directed to Reference 1, where these items are treated at some length as elements of the calculation procedure of which the subject procedure is a modification.

#### 1. THE SECTION THICKNESS DISTRIBUTION

The thickness distribution which is applied to the camber line herein described is that referred to as the "Standard Thickness Distribution" in Reference 1. The distribution is defined by two third-order polynomials, one from the leading edge to the point of maximum thickness, and another from there to the trailing edge. At the point of juncture, the thickness and the first and second derivatives of thickness are equated. In order to prevent a reflex curvature from occurring in the thickness distribution near the leading edge, the second derivative of thickness is set equal to zero at the leading edge. The thickness of the leading and trailing edges is independently specified so that it need not be the same at both edges. At the leading edge, the blade surface is completed with a circular arc. At the trailing edge, the blade surface is truncated by connecting the two endpoints with a straight line.

#### 2. CARTESIAN COORDINATES FOR THE BLADE

The preceding material has described the methods used to design individual blade sections. When located as desired relative to the blade stacking axis, the section coordinates are the coordinates of the streamsurface blade section. A series of sections on all streamsurfaces specifies the envelope of the blade, but the surface coordinates are not in a form convenient for manufacturing purposes. The calculation procedure uses a spline-curve to interpolate (or extrapolate) the coordinates of the blade surfaces for manufacturing purposes.

#### 3. SECTION PROPERTIES

The stacking axis of the blade is passed through each streamsurface section either at one of the edges or at a point specified relative to the centroid of the section. Because the streamsurface sections are in general non-planar, the centroids of the manufacturing sections will not generally lie precisely

on the stacking axis when the streamsurface sections are stacked on their centroids. By determining the locations of the centroids of the manufacturing sections so obtained, it is possible to estimate the offsets that must be applied when restacking the streamsurface sections to locate the manufacturing centroids as desired relative to the stacking axis.

To assist further in the mechanical analysis of the blade, the areas, second moments of area, principal axes, and principal second moments of area for both the streamsurface and manufacturing sections are also determined in the calculation procedure.

#### 4. BLADE CHARACTERISTICS

A calculation of the volume enclosed by the blade between the innermost and outermost streamsurfaces is made. In addition, quantities which describe the blade on cylindrical surfaces and which may be required in an aerodynamic analysis of the blade are computed as an option. The calculations are presented here because a typographical error undetected during editing of Reference 1 has impaired their usefulness in that Reference.

First, the angular position of the camber line with respect to the stack axis at a streamsurface-computing station intersection is specified in terms of  $\Phi$ , defined in Figure 1.

The physical passage blockage ( $B$ ) due to the presence of the blades is determined as a percentage of the passage circumference in terms of the number of blades in the blade row and  $\tau$ , the angle subtended on the cylindrical surface by each blade:

$$B = \frac{N\tau}{2\pi} \quad (25)$$

The blade lean angle,  $\epsilon$ , with respect to the radial direction at a given point is obtained from the slope of a spline-curve fit through the y-z Cartesian coordinates of the streamsurface section camber lines at the particular axial location.

Thus

$$\epsilon = \Phi - \text{Arctan} \left( \frac{dy}{dz} \right) \quad (26)$$

Two other quantities are needed to produce the proper mean-camber line angle on the cylindrical surface: The local computing station inclination,  $\mu$ , obtained from the specified station description; and the local streamsurface inclination,  $\gamma$ , obtained from the specified x-r streamsurface description. Together with the camber line angle on the streamsurface,  $\alpha_*$ , these quantities are employed in the following equation to calculate the proper cylindrical-surface section angle,  $\alpha_*^o$ :

$$\tan \alpha_*^o = \frac{\tan \gamma \tan \epsilon + \tan \alpha_*/\cos \gamma}{1 - \tan \mu \tan \gamma} \quad (27)$$

## SECTION V

### USE OF THE PROGRAM

Basic information required by the user to run the ARL computer program which incorporates the calculation procedure described in this report is given in this section. The various input data items are defined first, and the input data format is then specified. A description of the output data that may be expected is given. (Implementation of the program on a computing system is not discussed here, but in the section entitled "Computer Program Details".)

#### 1. DEFINITION OF INPUT DATA ITEMS

TITLE	An alphanumeric title of 72 characters that may be used to identify a run.
NLINES	The number of streamsurfaces which are defined and on which blade sections will be designed. Must satisfy $2 \leq \text{NLINES} \leq 15$ .
NSTNS	The number of computing stations at which the streamsurface radii are specified. Must satisfy $3 \leq \text{NSTNS} \leq 10$ .
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq \text{NZ} \leq 15$ .
NSPEC	The number of radially-disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq \text{NSPEC} \leq 15$ .
ISEGPT	The number of points to be used to define each segment of the camber line. $2 \leq \text{ISEGPT} \leq \text{Integer}(\frac{80}{\text{IRTE-IRLE}})$
NBLADE	The number of blades in the blade row.
ISTAK	If $\text{ISTAK} = 0$ , the blade will be stacked at the leading edge.  If $\text{ISTAK} = 1$ , the blade will be stacked at the trailing edge.  If $\text{ISTAK} = 2$ , the blade will be stacked at, or offset from, the section centroid.

IPUNCH      If IPUNCH = 0, the quantities necessary for aero-dynamic analysis of the resulting blade are not produced on punched cards.

              If IPUNCH = 1, these quantities are produced on punched cards.

IFPLOT      Where CALCOMP software is incorporated into the computing system, IFPLOT specifies the creation of precision plots. (Further information regarding the requirements for this are given in the section entitled "Computer Program Details.")

              If IFPLOT = 0, no plots will be produced.

              If IFPLOT = 1, a plot of the streamsurface sections will be produced. All NLINEs sections are shown superimposed. The origin for each section plot is offset from the centroid of the section by distances specified by DELX and DFLY. If IFPLOT = 2, a plot of the manufacturing sections will be produced. The origin is the blade stacking axis, and all NZ sections are shown superimposed.

              If IFPLOT = 3, both of the plots described for IFPLOT = 1 and 2 will be produced.

              If IFPLOT = 4, individual plots of each of the manufacturing sections will be produced. The axes are rotated clockwise by the section stagger angle for each plot.

IPRINT      The input data is always listed by the program. Details of the streamsurface and manufacturing sections are printed as prescribed by IPRINT.

              If IPRINT = 0, details of streamsurface and manufacturing sections are printed.

              If IPRINT = 1, details of streamsurface sections are printed.

              If IPRINT = 2, details of the manufacturing sections are printed.

ZINNER,  
ZOUTER      The NZ manufacturing sections are equispaced between z equals ZINNER and ZOUTER.

SCALE        When precision plots are produced, SCALE is the scale factor employed.

STACKX	The axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.
PLTSZE	The size (inches) of the plotter to be used in the creation of precision plots.
IRLE	The number of the computing station designated as the blade leading edge.
IRTE	The number of the computing station designated as the blade trailing edge.
NRADEV	The number of radii at which the non-dimensional deviation distribution is specified. $1 \leq NRADEV \leq 5$ .
NINC	The number of points which describe the incidence angle distribution. $1 \leq NINC \leq 15$ .
NSIGN	An integer which specifies the sign convention of the particular blade. Conventionally positive rotors and stators have NSIGN values of -1 and +1, respectively.
IFCA	If IFCA = 1, the factor m in the deviation angle rule is that of the NACA-65-series mean line (Figure 195, Reference 2).  If IFCA = 2, the factor m in the deviation angle rule is that of the circular-arc mean line.
IPASS	The number of initial values of $S/R_o$ which are to be used in the procedure to find the optimal camber line. $20 \leq IPASS \leq 50$ .
XKSHPE	The shape factor ( $K_{\delta_s}$ ) in the deviation equation.
SOLTOL	The solidity tolerance used in the iterative procedure to produce a consistent camber line.
NPTS	The number of points defining a particular chordwise deviation distribution. $1 \leq NPTS \leq 10$ .
RADEV	Radius at which a particular deviation distribution applies.
SM	An array of NPTS meridional chord fractions which, together with DEVCRV, specify a particular deviation distribution.
DEVCRV	An array of NPTS normalized deviation fractions which, together with SM, specify a particular deviation distribution.

RINC	An array of NINC radii which, together with XINC, specify the incidence distribution at the leading edge.
XINC	An array of NINC incidence angles which, together with RINC, specify the incidence distribution. Input positive for conventionally positive rotors and stators (see NSIGN).
DELDEV	An array of NINC angles which, together with RINC, specify the distribution of the "arbitrary extra deviation" term in the deviation determination. Input positive for conventionally positive rotors and stators (see NSJIN).
KPTS	The number of points provided to specify the shape of a computing station.  If KPTS = 1, the computing station is upright and linear.  If KPTS = 2, the computing station is linear and either upright or inclined.  If KPTS > 2, a spine curve is fitted through the points provided to specify the shape of the station.
IFANGS	If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station.  If IFANGS = 1, these calculations will be performed at that station.
XSTA	An array of KPTS axial coordinates (relative to an arbitrary origin) which, together with RSTA, specify the shape of a particular computing station.
RSTA	An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.
R	The streamsurface radii at NLINES locations at each of the NSTNS stations.
AIRANG	The relative air angles at NLINES locations at each of the NSTNS stations.

ZR	The variation of properties of the streamsurface blade sections is specified as a function of streamsurface number. The various quantities are then interpolated (or extrapolated) at each streamsurface. The streamsurfaces are numbered consecutively from the innermost outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.
YA	The fraction of meridional chord used as the leading edge in the calculation of the section chord for the solidity iteration on a particular streamsurface. If YA = 0., the true chord length is calculated. $0.0 \leq YA \leq 1.0$ .
YB	The increment in $S/R_o$ which, with SDIVR and IPASS, establishes the initial range of $S/R_o$ which is inspected in the determination of the optimal camber line on a particular streamsurface. May be positive or negative.
YC	If YC = 0., the radius of curvature at the leading edge of each camber line will be considered in the procedure to identify the camber line which maximizes the minimum radius of curvature.  If YC = 1.0, the radius of curvature at the leading edge will not be considered in this procedure.
YE	The maximum number of inflection points expected on a particular camber line. If the calculated minimum number is greater than YE, an informational diagnostic is printed.
RLE	The ratio of section leading edge radius to chord.
TC	The ratio of section maximum thickness to chord.
TE	The ratio of section trailing edge half-thickness to chord.
Z	The location of the section maximum thickness, as a fraction of camber line length.
SDIVR	The initial value of $S/R_o$ .
DELX, DELY	The stacking axis passes through the streamsurface blade sections, offset from the centroid, leading, or trailing edge by DELX and DELY in the x and y directions, respectively.

## 2. INPUT DATA FORMAT

Data input is by punched card, and three formats are used. The first card only is alphanumeric, using the first 72 columns of the card. Integers are placed in three-column fields, which start with Column 1. No decimal points are used, and the integer should be right-justified. Real numbers are placed in 12-column fields, which also start with Column 1. Decimal points should be included, and the numbers may be placed anywhere in the field.

In the following chart, one line corresponds to one card.

TITLE

NLINES NSTNS NZ NSPEC ISEGPT NBLADE ISTAK IPUNCH IFPLOT IPRINT

ZINNER ZOUTER SCALE STACKX PLTSZE

IRLE IRTE NRADEV NINC NSIGN IFCA IPASS

XKSHPE SOLTOL

NPTS

RADEV

SM DEVCRV } repeated NPTS times

RINC XINC DELDEV } repeated NINC times

KPTS IFANGS

XSTA RSTA } repeated KPTS times

R AIRANG } repeated NLINES times

ZR YA YB YC YE RLE

TC TE Z SDIVR DELX DELY } repeated NSPEC times

} repeated NRADEV times

} repeated NSTNS times

} repeated NSPEC times

Listing of a sample input data deck is included under  
"Example of Use of the Program."

## 3. OUTPUT DATA

Printed output from the program may be considered to consist of four sections: a printout of the input data, details of the camber line and blade section on each streamsurface, a

listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below.

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the results of the investigations of the  $S/R_o$  parameter. The initial table presents the results of the first iteration which is used to identify the range of  $S/R_o$  in which the minimum number of inflection points occur on the camber line. This range is in turn investigated with finer increments of  $S/R_o$  to determine the maximum value of the minimum radius of curvature. Then follow the details of the optimal camber line which has been identified by a third investigation of  $S/R_o$  with still finer parameter increments. These details include the deviation and solidity which have been calculated for this optimal  $S/R_o$ , and a description of the camber line in terms of coordinates, first and second derivatives, and the radii of curvature. Listed next are the parameters defining the blade section, some of which are computed and some of which are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the particular section, except that the meridional projection of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord, stagger angle, camber angle, section area, location of centroid of the section, second moments of area of the section about the centroid, orientation of the principal axes, and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. A line-printer plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page. Thus, the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give the proper blade section. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord, radius and location of center of the leading edge, section area, the second moments of area of the section about the centroid, and the principal second moments of area of the section about the centroid. The coordinates of points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at six degree intervals around the leading edge. Finally, the coordinates of the blade surfaces and points around the leading edge are shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area, the location of the centroid of the section, the second moments of area of the section about the centroid, the principal second moments of area of the section about the centroid, the orientation of the principal axes, and the section torsional constant. Then the coordinates of points on the blade section surfaces are listed, followed by 31 points around the leading edge.

Precision plots are produced if IFPLOT = 1, 2, 3 or 4 as described under the definition of IFPLOT given previously.

If IPUNCH = 1, the program punches the quantities required for aerodynamic analysis, together with identifying indices denoting station number and streamsurface number, on cards in the following format: 5 fields each of 12 locations for the quantities themselves, followed by 2 fields each of 3 locations for the indices.

## SECTION VI

### EXAMPLE OF USE OF THE PROGRAM

This section shows the use of the program to generate a compressor rotor with an inlet hub-to-tip ratio of 0.31, a rather steep hub ramp angle ( $32.5^\circ$ ), and a constant outer radius. The blade is defined by six computing stations, one at either edge and four internal. This results in a camber line composed of five segments. Six streamlines have been used to define the flow and hence the blade by means of the streamsurface blade sections. The computing-stations and streamsurfaces which define the blade are depicted in a stack-axis projection in Figure 2.

#### 1. INPUT DATA

The input data deck used for this example is listed below. Some points of interest are noted in the order in which they occur in the input.

As mentioned above, six streamsurface blade sections are used to define the blade. The streamsurface radii are specified at eight computing stations, the first and last of which are outside of the rotor. This ensures that the boundary conditions imposed on the spline-curve (zero curvature at the endpoints) have little influence on the shape of the curve representing the streamsurface within the blade. The useful relative air angles are specified at the six computing stations defining the blade. The computing stations within the blade are curved in an attempt to make the meridional projections of the camber line segments approximately equal. The parameters which define the streamsurface blade sections are given at six locations; that is, at every streamsurface. Twelve points are used to define each segment, which results in a camber line defined by a total of fifty-six points. (This number serves the purposes of this example well, but it would be advantageous to use more points if the precision-plot output is to be incorporated directly in the manufacturing procedure.) There are twenty blades in the particular blade row, stacked approximately on their streamsurface centroids. No punched output is requested. All optional sections of the printed output are to be printed, and superimposed section plots are to be produced on a plotter (with an 11-inch useful range) at two and one-half times full size.

Stations 2 and 7 are the leading and trailing edges of the blade, respectively. The deviation distribution is the same at all radii, since it is specified only at one radius. The incidence angles and the arbitrary extra deviation are specified

at six points for this rotor blade. The factor  $m$  in the deviation calculation is to be that of a circular-arc camber line. Thirty camber lines will initially be investigated in the effort to identify the optimal camber line, representing a broad range of the  $S/R_o$  parameter. The shape factor in the deviation calculation is unity, and the tolerance on solidity in the iteration for each camber line is 0.005.

The streamsurface radii and relative air angles have been determined from an aerodynamic analysis of the flow through the blade row. The leading edge of the blade has been established as the point from which the chord length, and thus the solidity, will be computed.

The increment in the  $S/R_o$  parameter has been initially set equal to  $\pm 0.04$  in the investigation to find the optimal camber line. This increment will automatically be reduced twice subsequently as the most favorable range of  $S/R_o$  is more closely scrutinized. It is anticipated that no inflection points will be required near the hub, while a single inflection point will probably be required in the mid and tip regions of the blade. The blade thickness distribution is determined by aerodynamic and mechanical factors. The leading edge radius and trailing edge half-thickness are set to approximately 0.005 inch, probably a practical minimum. Maximum thickness/chord ratios vary from 6 percent at the hub to 2.5 percent at the casing. The maximum thickness is placed in the rearward portion of the camber line, which helps to maintain a small leading edge wedge angle.

EXAMPLE - LCH HUE/TIF RATIC COMPRESSOR RCTCR DESIGN

6	8	7	6	12	20	2	0	3	C	
2.5				8.50		2.5			-7.05	11.0
2	7	1	6	-1	2	30				
1.						.005				
6										
3.3										
0.						.1				
0.2						.11				
0.4						.15				
.6						.22				
.8						.36				
1.						1.00				
2.68						6.37			2.	
3.84						5.57			2.	
5.05						4.85			2.	
6.42						4.2			2.	
7.75						3.92			2.	
8.5						3.65			2.	
1 0										
-5.						2.35				
2.35										
3.6454										
4.9893										
6.3E17										
7.7723										
8.5										
5 0										
-8.51						2.6514				
-8.5926						5.06E3				
-8.531						6.3989				
-8.3115						7.7861				
-8.161						8.5				
						2.6514	-40.9695			
						3.8041	-47.2370			
						5.0786	-50.8039			
						6.4169	-53.6378			
						7.7902	-57.2964			
						8.5000	-59.7859			
4 1										
-7.905						3.0363				
-8.000						5.07				
-7.96						6.48				
-7.725						8.5				
						3.03E3	-30.0198			
						4.0696	-37.2906			
						5.2456	-44.5116			
						6.4975	-51.0404			
						7.8091	-57.8178			
						8.5000	-61.3719			

4	1
-7.35	3.3893
-7.395	5.385
-7.415	6.565
-7.311	8.5
	3.3893 -20.0393
	4.3344 -28.9282
	5.4154 -38.6681
	6.5824 -47.7054
	7.8307 -56.2706
	8.5000 -60.2293

4	1
-6.861	3.7385
-6.801	5.49
-6.87	6.65
-6.94	8.5
	3.7385 -12.2698
	4.5798 -21.2618
	5.5662 -33.3334
	6.6591 -44.2126
	7.8459 -54.0832
	8.5000 -58.9884

4	1
-6.251	4.0884
-6.18	5.7
-6.3	6.725
-6.56	8.5
	4.0884 -5.4451
	4.8259 -13.8107
	5.7147 -27.6798
	6.7242 -40.6966
	7.8575 -51.6465
	8.5000 -57.5196

5	1
-5.665	4.4612
-5.5846	5.896
-5.7208	6.7945
-5.9516	7.8661
-6.134	8.5
	4.4612 11.5881
	5.0795 -7.0980
	5.8623 -25.6222
	6.7858 -40.0751
	7.8716 -51.3351
	8.5000 -56.5798

4	0
-5.52	4.5534
-5.35	5.2
-5.3	5.80
-5.7	8.5

4.5534					
5.1806					
5.9412					
6.5278					
7.8877					
8.5					
1.0	0.	0.04	0.	0.	.00155
.06	.00155	.56	-0.2	.01	
2.0	0.	.04	0.	0.	.00149
.0525	.00149	.59	-0.15	-.018	
3.0	0.	.04	0.	1.	.00143
.0423	.00143	.62	-0.3	.035	
4.	0.0	.04	0.0	1.0	.00137
.0325	.00137	.65	-1.3	.02	
5.0	0.0	.04	0.	1.0	.00131
.0265	.00131	.68	-2.0	.01	
6.	0	0.04	0.	1.0	.00125
.025	.00125	.70	-2.3	-.001	

## 2. OUTPUT DATA

The input data specified all optional output data, and a sample of each segment of the output is presented in this section. A brief description of some aspects of the output is presented below.

Shown first is the printout of the input data. This is followed by details of the first streamsurface blade section. The tables presenting the results of the  $S/R_0$  investigations are followed by a description of the camber line which has been selected. Then appear the details of, and a line-printer plot of, the normalized blade section, followed by the specifications of the section scaled to the proper dimensions. Printed first are the 56 points specified for each blade surface. Next appear the 31 points describing the leading edge radius. The final data for the streamsurface section are the equivalent Cartesian coordinates for these same points.

The format is repeated for each of the remaining streamsurface blade sections, but these results are not reproduced here. Subsequent to the streamsurface data are printed the quantities required for aerodynamic analysis at those stations where requested by the IFANGS parameter.

Details for the seven manufacturing sections defining the blade follow. Reproduced below is the output relating to the first (innermost) section. Properties of the section are followed by coordinates of 56 points on each surface and 31 points around the leading edge. It will be noted that the section centroid is not calculated to be exactly on the stacking axis. If it were desired to have the centroids of the manufacturing sections lie more nearly precisely on the stacking axis, the program would be rerun with either DELX and DELY offsets specified so that they would counteract the mislocation of the centroids previously determined, or with a slightly shifted location of the stack axis. However, the user must bear in mind that the final step in the design procedure is to obtain satisfactory coincidence of the blade with the stations defining its leading and trailing edges in the meridional plane. It is possible that a blade which had all manufacturing sections stacked precisely on their centroids at a particular stacking-axis location would have quite an undesirable meridional profile. There are tradeoffs, then, between the stacking preciseness and the coincidence of the calculated blade's edges with its assumed profile on the one hand, and the number of iterations it would require to find the truly optimal stack location and centroid offsets, on the other.

The input data specified superimposed precision plots of both the streamsurface sections and the manufacturing sections. These plots are reproduced (at reduced size) as Figures 3 and 4,

respectively. It is of interest to refer also to Figure 2. The innermost manufacturing plane is well below the lowest point on the hub streamsurface section in the plane of the stacking axis. The Cartesian coordinates of this streamsurface section show that the lowest point on the section (the 14th point on the leading edge) is at  $Z = 2.57224$ . The streamsurface radius at this point is 2.6514, and the innermost manufacturing plane is at  $Z = 2.5$ . Thus, at the leading edge, the extrapolation required to define the manufacturing section is somewhat smaller than might first appear. At the trailing edge, extrapolation is required for the first three manufacturing sections. The streamsurface radius at the casing and the Z-coordinate for the outermost manufacturing plane both equal 8.5; however, the Z-coordinates of the blade section are all actually below 8.5. Thus, the outermost section too is defined completely by extrapolation. Of course, portions of the blade that are defined by extrapolation do not appear on the final blade, but facilitate manufacture.

USAF "ARL(LF) ARBITRARY CAMBER LINE PROGRAM

\*\*\*\*\* EXAMPLE - LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN \*\*\*\*\*

TITLE	=	6
NUMBER OF STREAMSURFACES	=	6
NUMBER OF STATIONS	=	6
NUMBER OF CONSTANT-Z PLANES	=	7
NUMBER OF BLADE DATA POINTS	=	6
NUMBER OF POINTS PER SEGMENT	=	12
NUMBER OF BLADES IN BLADE RCH	=	20
ISTAK	=	2
IPUNCH	=	0
IPLOT	=	3
IPRINT	=	0
ZINNER	=	2.5000
ZOUTER	=	3.5000
SCALE	=	2.5000
STACKX	=	-7.0500
PLTSIZE	=	11.0000
LEADING EDGE STATION NUMBER	=	2
TRAILING EDGE STATION NUMBER	=	7
RADI SPECIFYING DEVIATION	=	1
RADI SPECIFYING INCIDENCE	=	6
SENSE OF ROTATION INDICATOR	=	-1
DEVIATION CALCULATION INDEX	=	2
NUMBER OF INITIAL S/R TRIALS	=	30
SHAPE FACTOR	=	1.0000
SOLICITY TOLERANCE	=	*.0050

DEVIATION CURVE 1 NUMBER OF POINTS = 6 RADIUS = 3.0000

POINT	NORMALIZED MERIDIONAL CHCRD	NORMALIZED DEVIATION DISTRIBUTION
1	0.0000	*1000
2	*2000	*1100
3	*4000	*1500
4	*6000	*2200
5	*8000	*3800
6-	1.0000	1.0500

INCIDENCE AND EXTRA DEVIATION DISTRIBUTION

INLET RADIUS	INCIDENCE	EXTRA DEVIATION
2.6800	6.370	2.000
3.0400	5.570	2.000
5.0900	4.850	2.000
6.4200	4.200	2.000
7.7900	3.920	2.000
8.5000	3.690	2.000

## STREAMSURFACE GEOMETRY SPECIFICATION

COMPUTING STATION 1 NUMBER OF DESCRIBING POINTS= 2 IFANGS( 1)= 0

DESCRIPTION X	STREAMLINE NUMBER	RADIUS	AIR ANGLE
-9.0900	2.3500	1	2.3500
-9.0000	3.3500	2	3.6454
		3	4.9893
		4	6.3617
		5	7.7723
		6	8.5000

COMPUTING STATION 2 NUMBER OF DESCRIBING POINTS= 5 IFANGS( 2)= 0

DESCRIPTION X	STREAMLINE NUMBER	RADIUS	AIR ANGLE
-8.5100	2.6514	1	2.6514
-8.5926	5.0663	2	3.0041
-8.5310	6.3989	3	5.0786
-8.3115	7.7861	4	6.4109
-8.1610	8.5000	5	7.7602
		6	8.5000

COMPUTING STATION 3 NUMBER OF DESCRIBING POINTS= 4 IFANGS( 3)= 1

DESCRIPTION X	STREAMLINE NUMBER	RADIUS	AIR ANGLE
-7.9050	3.0363	1	3.0363
-8.0000	5.0700	2	4.0696
-7.9600	6.4800	3	5.2456
-7.7250	8.5000	4	6.4975
		5	7.8091
		6	8.5000

COMPUTING STATION 4 NUMBER OF DESCRIBING POINTS= 4 IFANGS( 4)= 1

DESCRIPTION X	STREAMLINE NUMBER	RADIUS	AIR ANGLE
-7.3500	3.3893	1	3.3893
-7.3950	5.3850	2	4.344
-7.4150	6.5650	3	5.4154
-7.3110	8.5000	4	6.5624
		5	7.5307
		6	8.5000

COMPUTING STATION 5		NUMBER OF DESCRIBING POINTS= 4		IFANGS( 5)= 1
DESCRIPTION X R	STREAMLINE NUMBER	RADIUS	AIR ANGLE	
-6.0010	3.1305	1	3.7385	-12.2698
-6.8010	5.4900	2	4.5798	-21.2618
-6.8700	6.6500	3	5.5662	-33.3334
-6.9400	8.5000	4	6.6591	-44.2126
		5	7.0459	-54.0832
		6	8.5100	-56.5864

COMPUTING STATION 6		NUMBER OF DESCRIBING POINTS= 4		IFANGS( 6)= 1
DESCRIPTION X R	STREAMLINE NUMBER	RADIUS	AIR ANGLE	
-6.2510	4.0884	1	4.0684	-5.4451
-6.1800	5.7000	2	4.8259	-13.8107
-6.3000	6.7250	3	5.7147	-27.6798
-6.5600	8.5000	4	6.7242	-40.6966
		5	7.8575	-51.6465
		6	8.5100	-57.5196

COMPUTING STATION 7		NUMBER OF DESCRIBING POINTS= 5		IFANGS( 7)= 1
DESCRIPTION X R	STREAMLINE NUMBER	RADIUS	AIR ANGLE	
-5.6650	4.4612	1	4.4612	11.5881
-5.5846	5.8960	2	5.0795	-7.0960
-5.7208	6.7945	3	5.8623	-25.6222
-5.9516	7.8661	4	6.7258	-40.0751
-6.1340	8.5000	5	7.8716	-51.3351
		6	8.5100	-56.5758

COMPUTING STATION 8		NUMBER OF DESCRIBING POINTS= 4		IFANGS( 8)= 0
DESCRIPTION X R	STREAMLINE NUMBER	RADIUS	AIR ANGLE	
-5.5200	4.5534	1	4.5534	-0.0000
-5.3500	5.2000	2	5.1406	-0.0000
-5.3000	5.8000	3	5.9412	-0.0000
-5.7000	8.5000	4	6.8378	-0.0000
		5	7.6677	-0.0000
		6	8.5000	-0.0000

## SECTION GEOMETRY SPECIFICATION

STREAMLINE NUMBER	SLO CL/FI	IN. CEL S/RC	CONS ID LE RC CRV	NC.ALC INFL. FTS	LE RADIUS /CHCRC	MAX THICK /Z*CHCRC	PCINT CF MAX THICK OF /2*CHCRC	START VAL OF S/F	X STACK OFFSET CFFSET	Y STACK OFFSET CFFSET
1.00	1.000	.0040	0.0000	0.0000	.00155	.06000	.00155	.5600	.010000	.000000
2.00	1.000	.0040	0.0000	0.0000	.00149	.05250	.00149	.5900	.010000	.000000
3.00	1.000	.0040	0.0000	0.0000	.00143	.04230	.00143	.6200	.010000	.000000
4.00	1.000	.0040	0.0000	0.0000	.00137	.03250	.00137	.6500	.010000	.000000
5.00	1.000	.0040	0.0000	0.0000	.00131	.022650	.00131	.6800	.010000	.000000
6.00	1.000	.0040	0.0000	0.0000	.00125	.012500	.00125	.7000	.010000	.000000

STREAMSURFACE 1  
ITERATION 1  
\*\*\*\*

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INVENTAI S/B = 6400

**ANSWER**  $\Delta L \text{ S/R} = -0.2053$  INCREMENTAL S/R = +0.4000  
 PASS NC. NC. CF INFLECTION PTS MIN. RADIUS OF CURVATURE

STREAMSURFACE 1  
ITERATION 2  
\*\*\*\*\*

INITIAL S/R = 0.0000	NO. OF INFLECTION PTS	INCREMENTAL S/R = 0.110	MIN. RADIUS OF CURVATURE
1	1	• 387	
2	0	• 350	
3	0	• 393	
4	0	• 396	
5	0	• 399	
6	0	• 402	
7	0	• 405	
8	0	• 408	
9	0	• 412	
10	0	• 415	
11	0	• 418	
12	0	• 422	
13	0	• 425	
14	0	• 428	
15	0	• 433	
16	0	• 436	
17	0	• 440	
18	0	• 444	
19	0	• 448	
20	0	• 452	
21	0	• 456	
22	0	• 460	
23	0	• 464	
24	0	• 468	
25	0	• 472	
26	0	• 476	
27	0	• 480	
28	0	• 484	
29	2	• 488	
30	2	• 492	

OPTIMAL SECTION

FINAL S/R = .3025

ITERATIONS	CH SOLICITY	ITERATION 1	DEVIATION 1	DEVIATION 2	DEVIATION = 0.666	SOLICITY = 3.1200	ITERATION	CH SOLICITY	ITERATION 1	DEVIATION 1	DEVIATION 2	DEVIATION = 0.666	SOLICITY = 3.1211
PCIN1	NCRPLAIZED MERIDIONAL COORDINATE	TANGENTIAL COORDINATE	CURVATURE	CURVATURE	CURVATURE	CURVATURE	PCIN1	NCRPLAIZED MERIDIONAL COORDINATE	TANGENTIAL COORDINATE	CURVATURE	CURVATURE	CURVATURE	CURVATURE
1	0.0000	C.1000	-6053	-6053	-6506	-6506	1	0.0000	C.1000	-6053	-6053	-6506	-6506
2	*C193	-L132	-6766	-6766	-6466	-6466	2	*C193	-L132	-6766	-6766	-6466	-6466
3	*0387	-C262	-6643	-6643	-6427	-6427	3	*0387	-C262	-6643	-6643	-6427	-6427
4	*C580	-C389	-6516	-6516	-6363	-6363	4	*C580	-C389	-6516	-6516	-6363	-6363
5	*0773	-C514	-6356	-6356	-6349	-6349	5	*0773	-C514	-6356	-6356	-6349	-6349
6	*0967	-C636	-6274	-6274	-6309	-6309	6	*0967	-C636	-6274	-6274	-6309	-6309
7	*1160	-C756	-6152	-6152	-6270	-6270	7	*1160	-C756	-6152	-6152	-6270	-6270
8	*1353	-C874	-6021	-6021	-6231	-6231	8	*1353	-C874	-6021	-6021	-6231	-6231
9	*1547	-C950	-5911	-5911	-6152	-6152	9	*1547	-C950	-5911	-5911	-6152	-6152
10	*1740	-1103	-5792	-5792	-6152	-6152	10	*1740	-1103	-5792	-5792	-6152	-6152
11	*1933	-1213	-5673	-5673	-6113	-6113	11	*1933	-1213	-5673	-5673	-6113	-6113
12	*2127	-1322	-5556	-5556	-6074	-6074	12	*2127	-1322	-5556	-5556	-6074	-6074
13	*2304	-1420	-5440	-5440	-6089	-6089	13	*2304	-1420	-5440	-5440	-6089	-6089
14	*2481	-1515	-5306	-5306	-7905	-7905	14	*2481	-1515	-5306	-5306	-7905	-7905
15	*2659	-1608	-5159	-5159	-8021	-8021	15	*2659	-1608	-5159	-5159	-8021	-8021
16	*2836	-1698	-4955	-4955	-9736	-9736	16	*2836	-1698	-4955	-4955	-9736	-9736
17	*3013	-1765	-4814	-4814	-10692	-10692	17	*3013	-1765	-4814	-4814	-10692	-10692
18	*3191	-1868	-4617	-4617	-11562	-11562	18	*3191	-1868	-4617	-4617	-11562	-11562
19	*3368	-1948	-4404	-4404	-12483	-12483	19	*3368	-1948	-4404	-4404	-12483	-12483
20	*3545	-2025	-4174	-4174	-13399	-13399	20	*3545	-2025	-4174	-4174	-13399	-13399
21	*3723	-2096	-3929	-3929	-14314	-14314	21	*3723	-2096	-3929	-3929	-14314	-14314
22	*3900	-2164	-3667	-3667	-15230	-15230	22	*3900	-2164	-3667	-3667	-15230	-15230
23	*4077	-2226	-3386	-3386	-16446	-16446	23	*4077	-2226	-3386	-3386	-16446	-16446
24	*4253	-2263	-3116	-3116	-16600	-16600	24	*4253	-2263	-3116	-3116	-16600	-16600
25	*4428	-2326	-2873	-2873	-17214	-17214	25	*4428	-2326	-2873	-2873	-17214	-17214
26	*4604	-2384	-2654	-2654	-1749	-1749	26	*4604	-2384	-2654	-2654	-1749	-1749
27	*4779	-2429	-2461	-2461	-1823	-1823	27	*4779	-2429	-2461	-2461	-1823	-1823
28	*4954	-2471	-2254	-2254	-1817	-1817	28	*4954	-2471	-2254	-2254	-1817	-1817
29	*5130	-2510	-2152	-2152	-1751	-1751	29	*5130	-2510	-2152	-2152	-1751	-1751
30	*5305	-2546	-2036	-2036	-1866	-1866	30	*5305	-2546	-2036	-2036	-1866	-1866
31	*5481	-2561	-1945	-1945	-1920	-1920	31	*5481	-2561	-1945	-1945	-1920	-1920
32	*5656	-2615	-1881	-1881	-2954	-2954	32	*5656	-2615	-1881	-1881	-2954	-2954
33	*5832	-2647	-1842	-1842	-1469	-1469	33	*5832	-2647	-1842	-1842	-1469	-1469
34	*6007	-2680	-1828	-1828	-3023	-3023	34	*6007	-2680	-1828	-1828	-3023	-3023
35	*6182	-2712	-1816	-1816	-1369	-1369	35	*6182	-2712	-1816	-1816	-1369	-1369
36	*6358	-2743	-1760	-1760	-2715	-2715	36	*6358	-2743	-1760	-1760	-2715	-2715
37	*6534	-2774	-1721	-1721	-4061	-4061	37	*6534	-2774	-1721	-1721	-4061	-4061
38	*6710	-2804	-1618	-1618	-5407	-5407	38	*6710	-2804	-1618	-1618	-5407	-5407
39	*6886	-2832	-1531	-1531	-753	-753	39	*6886	-2832	-1531	-1531	-753	-753
40	*7061	-2857	-1400	-1400	-659	-659	40	*7061	-2857	-1400	-1400	-659	-659
41	*7237	-2881	-1246	-1246	-445	-445	41	*7237	-2881	-1246	-1246	-445	-445
42	*7413	-2901	-1068	-1068	-791	-791	42	*7413	-2901	-1068	-1068	-791	-791
43	*7589	-2918	-0687	-0687	-2137	-2137	43	*7589	-2918	-0687	-0687	-2137	-2137
44	*7764	-2921	-0642	-0642	-3463	-3463	44	*7764	-2921	-0642	-0642	-3463	-3463
45	*7940	-2940	-0353	-0353	-4829	-4829	45	*7940	-2940	-0353	-0353	-4829	-4829
46	*8127	-2945	-0107	-0107	-5737	-5737	46	*8127	-2945	-0107	-0107	-5737	-5737
47	*8315	-2944	-0157	-0157	-6644	-6644	47	*8315	-2944	-0157	-0157	-6644	-6644
48	*8502	-2938	-0517	-0517	-7552	-7552	48	*8502	-2938	-0517	-0517	-7552	-7552

49	• 8689
50	• 8876
51	• 9064
52	• 9251
53	• 9438
54	• 9625
55	• 9813
56	1 • 0000
	• 2925
	• 2906
	• 1268
	1 • 9368
	2 • 2975
	• 2880
	• 1579
	• 1967
	2 • 163
	• 2846
	• 2806
	• 2757
	• 2755
	2 • 2061
	• 2373
	• 2755
	2 • 2958
	2 • 3906
	2 • 4934
	• 3650
	• 4866
	2 • 4968
	• 548
	• 528
	• 512
	• 500

STREAM SURFACE GEOMETRY ON STREAMLINE NUMBER 1

BET1	= -34.579	(BLADE INLET ANGLE.)
BET12	= 20.254	(BLADE OUTLET ANGLE.)
YZERO	= .00155	(BLADE LEADING EDGE RADIUS AS A FRACTION OF CHORD.)
T	= .06000	(BLADE MAXIMUM THICKNESS AS A FRACTION OF CHORD.)
YCHE	= .00155	(BLADE TRAILING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.)
Z	= .5600	(LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN LINE.)
GCRC	= 3.3719	(MERIDIONAL CHORD OF SECTION.)

NORMALISED RESULTS - ALL THE FOLLOWING REFER TO A BLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY

BLADE CHORD = 1.0325

STAGGER ANGLE = -14.745

CARRIER ANGLE = -54.833

SECTION AREA = .04394

LOCATION OF CENTROID RELATIVE TO LEADING EDGE

XBAR = .50573  
YEAR = -.22597

SECOND MOMENTS OF AREA ABOUT CENTROID

IX	= .00021
IY	= .00233
IXY	= -.00063

ANGLE OF INCLINATION OF (CONE) PRINCIPAL AXIS TO X\* AXIS = 15.355

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

IPX	= .00004	(AT -15.355 WITH 'X' AXIS)
IPY	= .00250	(AT -15.355 WITH 'Y' AXIS)

POINT NUMBER	X	Y	Z	MEAN LINE DATA	
1	.00160	0.00000-34.579	.00320	0.00251	.00132
2	.02069	-01.318-34.089	.00665	.02276	.01042
3	.04018	-02.611-33.596	.01007	.04297	.02192
4	.05948	-03.881-33.101	.01345	.06315	.03310
5	.07877	-05.126-32.603	.01677	.08328	.04420
6	.09806	-06.349-32.103	.02004	.10330	.05500
7	.11735	-07.547-31.600	.02324	.12344	.06557
8	.13664	-08.722-31.095	.02637	.14345	.07535
9	.15593	-09.874-30.588	.02941	.16341	.08600
10	.17522	-11.003-30.079	.03236	.18333	.09603
11	.19451	-12.109-29.568	.03522	.20320	.10577
12	.21360	-13.192-28.055	.03796	.22302	.11533
13	.23150	-14.165-28.545	.04038	.24115	.12391

SURFACE COORDINATE DATA

POINT NUMBER	X	Y	Z	SURFACE COORDINATE DATA	
1	.00160	0.00000-34.579	.00320	0.0069	.00132
2	.02069	-01.318-34.089	.00665	.01903	.01593
3	.04018	-02.611-33.596	.01007	.03740	.03030
4	.05948	-03.881-33.101	.01345	.05580	.04464
5	.07877	-05.126-32.603	.01677	.07425	.05033
6	.09806	-06.349-32.103	.02004	.09273	.07197
7	.11735	-07.547-31.600	.02324	.11126	.08587
8	.13664	-08.722-31.095	.02637	.12983	.09651
9	.15593	-09.874-30.588	.02941	.14845	.11140
10	.17522	-11.003-30.079	.03236	.16711	.12403
11	.19451	-12.109-29.568	.03522	.18582	.13640
12	.21360	-13.192-28.055	.03796	.20459	.14051
13	.23150	-14.165-28.545	.04038	.22165	.15936

POINT  
NUMBER

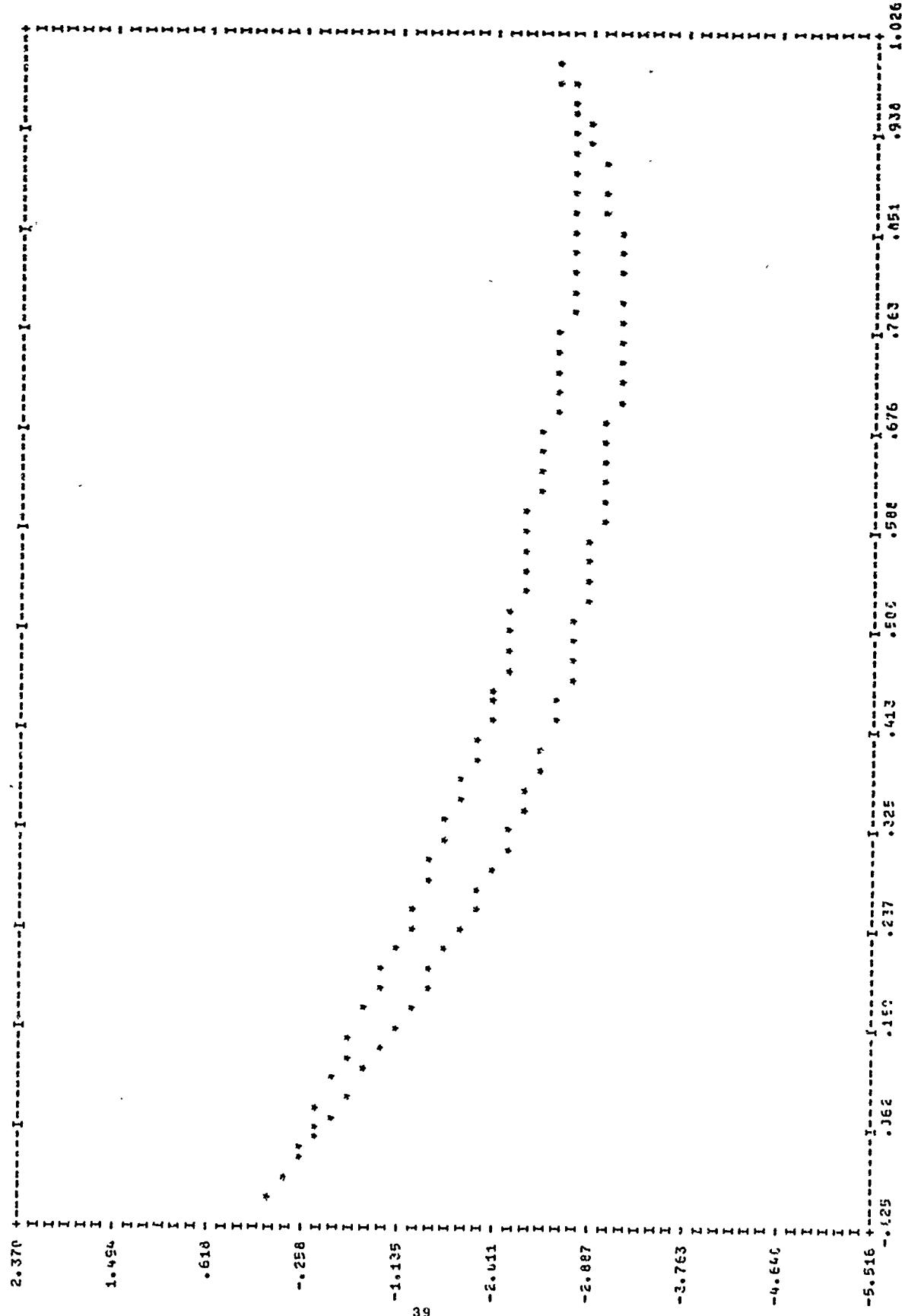
M E A N L I N E D A T A

SURFACE COORDINATE DATA

	X	Y	ANGLE	THICKNESS	X <sub>S</sub>	Y <sub>S</sub>	X <sub>P</sub>	Y <sub>P</sub>
14	-24919	-15116	-27.956	• 04265	• 25920	-• 13231	• 23919	-• 17001
15	-26669	-16042	-27.291	• 04489	• 27718	-• 14048	• 25669	-• 10043
16	-28459	-16941	-26.541	• 04698	• 29506	-• 14839	• 27409	-• 19043
17	-30228	-17809	-25.706	• 04695	• 31290	-• 15604	• 29166	-• 20044
18	-31958	-18644	-24.783	• 05079	• 33062	-• 16338	• 30933	-• 20950
19	-33767	-19442	-23.768	• 05250	• 34825	-• 17040	• 32705	-• 21045
20	-35537	-20201	-22.657	• 05406	• 36572	-• 17706	• 34495	-• 22697
21	-37306	-20919	-21.446	• 05553	• 38321	-• 18334	• 36291	-• 23503
22	-39076	-21551	-20.136	• 05683	• 40054	-• 18923	• 38098	-• 24250
23	-40845	-22215	-18.718	• 05795	• 41776	-• 19469	• 39915	-• 24961
24	-42595	-22764	-17.317	• 05900	• 43474	-• 19968	• 41718	-• 25600
25	-44346	-23308	-16.031	• 05986	• 45173	-• 20432	• 43520	-• 26185
26	-46097	-23792	-14.866	• 06058	• 46874	-• 20864	• 45319	-• 26719
27	-47847	-24239	-13.826	• 06116	• 48570	-• 21270	• 47116	-• 27204
28	-49558	-24655	-12.918	• 06159	• 50206	-• 21653	• 48909	-• 27655
29	-51348	-25043	-12.144	• 06187	• 51999	-• 22019	• 50697	-• 28068
30	-53098	-25410	-11.506	• 06200	• 53717	-• 22372	• 52480	-• 28447
31	-54849	-25758	-11.000	• 06198	• 55441	-• 22716	• 54257	-• 28799
32	-56559	-26092	-10.651	• 06179	• 57170	-• 23056	• 56026	-• 29126
33	-58350	-26438	-10.435	• 06145	• 58906	-• 23396	• 57793	-• 29439
34	-60100	-26738	-10.361	• 06094	• 60648	-• 23741	• 59552	-• 29736
35	-61854	-27058	-10.294	• 06026	• 62392	-• 24093	• 61315	-• 30024
36	-63608	-27374	-10.094	• 05544	• 64126	-• 24448	• 63087	-• 30300
37	-65361	-27661	-9.763	• 05845	• 65857	-• 24801	• 64666	-• 30561
38	-67115	-27976	-9.300	• 05729	• 67578	-• 25149	• 66652	-• 30003
39	-68869	-28254	-8.703	• 05596	• 69292	-• 25478	• 68445	-• 31020
40	-70622	-28512	-7.970	• 05447	• 71000	-• 25814	• 70245	-• 31209
41	-72376	-28744	-7.102	• 05282	• 72703	-• 26123	• 72050	-• 31365
42	-74120	-28947	-6.997	• 05100	• 74401	-• 26412	• 73859	-• 31483
43	-75884	-29117	-6.953	• 04901	• 76095	-• 26676	• 75672	-• 31559
44	-77637	-29250	-3.671	• 04685	• 77787	-• 26912	• 77467	-• 34588
45	-79391	-29341	-2.49	• 04453	• 79478	-• 27146	• 79304	-• 31566
46	-81260	-29388	-1.611	• 04187	• 81262	-• 27295	• 81237	-• 31481
47	-83128	-29360	-1.126	• 03501	• 83090	-• 27430	• 83166	-• 31339
48	-84997	-29313	-2.950	• 03595	• 84904	-• 27518	• 85089	-• 31108
49	-86865	-29185	-4.801	• 03266	• 86726	-• 27557	• 87004	-• 30014
50	-88734	-28993	-6.889	• 02920	• 88550	-• 27544	• 88909	-• 30443
51	-90602	-28733	-8.974	• 02550	• 90403	-• 27474	• 90801	-• 29992
52	-92471	-28402	-11.130	• 02156	• 92262	-• 27344	• 92679	-• 29460
53	-94339	-27997	-13.347	• 01738	• 94138	-• 27151	• 94540	-• 28042
54	-96208	-27514	-15.614	• 01294	• 96033	-• 26891	• 96362	-• 28137
55	-98076	-26951	-17.921	• 00822	• 97950	-• 26560	• 98022	-• 27342
56	-99945	-26305	-20.254	• 00320	• 99889	-• 26154	• 1.00000	-• 26455

NORMALISED PLCT OF SECTION NUMBER 1

SCALES - 'x' IS SHOWN TIMES 10 TO THE POWER OF -6 'y' IS SHOWN TIMES 10 TO THE POWER OF 1



**CIMENSIGNAL RESULTS - ALL RESULTS REFER TO A PLACE OF SPECIFIED CHORO**

BLACE CHCRC = 3.48493E+03

$$\epsilon_{\text{analysis}} = \epsilon / 0.016 / E = 0.7$$

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## SECOND COMPONENTS OF AREA ABCUT CENTROID

$$1x = 2.689375 \cdot 10^{-2}$$

1 X Y = -8.121333E-02

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IF X = 4.56332E-03 (AT-15.355 WITH Y' AXIS)
IF Y = 1.23544F-01 (AT-15.355 WITH Y' AXIS)

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FT AC SUCTION-----SURFACE PRESSURE-----SURFACE Y X Y

1	-1.70682E+00	7.57486E-01
2	-1.66381E-01	-1.71293E+00
3	-1.57028E+00	-1.58616E+01
4	-1.47164E+00	-1.46491E+01
5	-1.25995E+00	-1.34608E+01
6	-1.12899E-01	-1.21477E+00
7	-1.06425E+00	-1.05710E+00
8	-1.01642E-01	-9.62695E-01
9	-1.01642E-01	-9.86698E-01
10	-1.03012E+01	-1.02003E+01
11	-1.05283E-01	-9.67241E-01
12	-9.66455E-01	-9.41275E-01
13	-9.02155E-01	-8.24516E-01
14	-8.60474E-01	-7.20289E-01
15	-7.80627E-01	-6.53745E-01
16	-7.00503E-01	-5.60554E-01
17	-6.60220E-01	-4.70756E-02
18	-6.21814E-01	-3.80536E-02
19	-5.41099E-01	-2.53600E-02
20	-4.81293E-01	-1.64519E-01
21	-4.23122E-01	-1.23076E-01
22	-3.64704E-01	-1.23076E-01
23	-3.06645E-01	-1.24939E-01
24	-2.47644E-01	-1.34748E-01
25	-1.92104E-01	-1.20682E-01
26	-1.47546E-02	-1.96336E-02
27	-7.72876E-02	-1.65996E-01
28	2.80587E-02	-5.82585E-03
29	1.54111E-01	-4.01114E-02
30	1.41207E-01	-2.59142E-01
31	1.54111E-01	-2.14207E-01
32	1.70966E-01	-2.33440E-01
33	3.88517E-01	-2.52409E-01
34	5.05324E-01	-2.65544E-01
35	4.71513E-01	-5.92613E-01
36	6.21155E-01	-5.74954E-02
37	7.36165E-01	-1.65058E-01
38	8.50555E-01	-1.37543E-01
39	6.44632E-01	-1.52238E-01
40	1.08640E+00	-1.62955E-01
41	1.20961E+00	-1.67259E-01
42	1.6608E-01	-1.65453E-01
43	1.33332E+00	-1.30217E-01
44	1.13756E-01	-1.02414E-01
45	1.46100E+00	-1.58748E+00
46	1.05040E+01	-1.02544E+00
47	1.08640E+00	-1.08899E+00
48	1.14757E+00	-1.14757E+00
49	1.21639E+00	-1.21639E+00
50	1.27705E+01	-1.27705E+01
51	1.49360E+01	-1.49360E+01
52	1.10580E+01	-1.10580E+01
53	1.45895E+00	-1.45895E+00
54	1.52264E+00	-1.52264E+00
55	1.58745E+00	-1.58745E+00
56	1.65525E+00	-1.65525E+00

## FCINTS DESCRIBING LEAVING EGGE RADIUS

FCINT	NC.	X	Y						
1	-1.	7.1293E+00	7.5748E-01						
2	-1.	7.1236E+00	7.5762E-01						
3	-1.	7.1378E+00	7.5822E-01						
4	-1.	7.1415E+00	7.5865E-01						
5	-1.	7.1447E+00	7.5911E-01						
6	-1.	7.1474E+00	7.5961E-01						
7	-1.	7.1496E+00	7.6011E-01						
8	-1.	7.1512E+00	7.6066E-01						
9	-1.	7.1522E+00	7.6123E-01						
10	-1.	7.1526E+00	7.6180E-01						
11	-1.	7.1525E+00	7.6236E-01						
12	-1.	7.1517E+00	7.6252E-01						
13	-1.	7.1504E+00	7.6347E-01						
14	-1.	7.1485E+00	7.6400E-01						
15	-1.	7.1461E+00	7.6454E-01						
16	-1.	7.1431E+00	7.6499E-01						
17	-1.	7.1396E+00	7.6544E-01						
18	-1.	7.1357E+00	7.6585E-01						
19	-1.	7.1314E+00	7.6622E-01						
20	-1.	7.1268E+00	7.6654E-01						
21	-1.	7.1218E+00	7.6691E-01						
22	-1.	7.1168E+00	7.6702E-01						
23	-1.	7.1126E+00	7.6718E-01						
24	-1.	7.1056E+00	7.6729E-01						
25	-1.	7.1030E+00	7.6733E-01						
26	-1.	7.0954E+00	7.6731E-01						
27	-1.	7.0872E+00	7.6724E-01						
28	-1.	7.0632E+00	7.6711E-01						
29	-1.	7.0779E+00	7.6692E-01						
30	-1.	7.0728E+00	7.6667E-01						
31	-1.	7.0680E+00	7.6636E-01						

## CARTESIAN COORDINATES ON STREAMSURFACE 1

PCINT	NC	ZS	XS	YS	2P	XF	YF		
1		2.0E7578E+00	-1.049008E+00	0.79391E-01	2.0E7486E+00	-1.04527E+00	0.69943E-01		
2		2.0E2081E+00	-1.02315E+00	0.618172E+00	2.0E1872E+00	-1.03225E+00	0.30152E-01		
3		2.0E6530E+00	-1.032471E+00	0.20276E-01	2.0E178E+00	-1.03468E+00	0.5046E-01		
4		2.0E70925E+00	-1.026722E+00	0.0800E-01	2.0E171E+00	-1.028816E+00	0.51002E-01		
5		2.0E75268E+00	-1.020996E+00	0.61579E-01	2.0E1574E+00	-1.023567E+00	0.1173JE-31		
6		2.0E79558E+00	-1.015281E+00	0.32394E-01	2.0E1370E+00	-1.018309E+00	4.72643E-01		
7		2.0E83795E+00	-1.019581E+00	0.53292E-01	2.0E8270E+00	-1.013042E+00	4.3385EE-01		
8		2.0E87981E+00	-1.038952E+00	4.074346E-01	2.0E86671E+00	-1.022765E+00	3.95344E-01		
9		2.0E92113E+00	-1.082233E+01	4.045503E-01	2.0E80581E+00	-1.024775E+00	3.57260E-01		
10		2.0E96194E+00	-1.025447E+01	4.016797E-01	2.0E84435E+00	-1.071721E-01	3.1927E-01		
11		2.0E0224E+00	-0.691888E-01	3.088229E-01	2.0E88234E+00	-1.085567E-01	2.082142E-01		
12		2.0E4221E+00	-0.128522E-01	3.059610E-01	2.0E901981E+00	-1.06253E-01	2.04524E-01		
13		2.0E7802E+00	-0.613188E-01	3.03904E-01	2.0E92376E+00	-1.016176E-01	2.017076E-01		
14		2.0E11357E+00	-0.699688E-01	3.068275E-01	2.0E980736E+00	-1.068807E-01	1.070735E-01		
15		2.0E14865E+00	-0.588182E-01	2.083013E-01	2.0E12065E+00	-1.017373E-01	1.04639E-01		
16		2.0E18328E+00	-0.678822E-01	2.09803E-01	2.0E15267E+00	-1.067620E-01	1.04960E-01		
17		2.0E21746E+00	-0.57193E-01	2.034006E-01	2.018646E+00	-1.017614E-01	0.36502E-02		

PCINT	NC	2S	XS	YS	2P	XF	YF
			2S	2P	3.21566E+00	3.21566E+00	3.21566E+00
12	15	3.25119E+00	-5.06751E-01	2.10564E-01	1.67520E-01	-5.67343E-01	5.37112E-02
15	20	3.28455E+00	-4.56573E-01	1.66667E-01	1.66667E-01	-5.16759E-01	2.48661E-02
20	21	3.21739E+00	-4.06667E-01	1.66147E-01	2.28390E+00	-4.65971E-01	-2.93534E-03
21	22	3.34956E+00	-3.57064E-01	1.45434E-01	2.21623E+00	-4.14651E-01	-2.53572E-02
22	23	3.28263E+00	-3.07756E-01	1.25904E-01	2.24657E+00	-4.42622E-01	-5.42622E-02
23	24	3.41381E+00	-2.58756E-01	1.67566E-01	2.38057E+00	-4.11713E-01	-7.76772E-02
24	25	3.44502E+00	-2.10338E-01	9.5985E-02	1.41202E+00	-4.60406E-01	-9.54429E-02
25	26	3.47615E+00	-1.62093E-01	7.47768E-02	1.44499E+00	-2.06121E-01	-1.18963E-01
26	27	3.50722E+00	-1.13659E-01	5.8230CE-02	1.47665E+00	-2.10575E-01	-1.37239E-01
27	28	3.53822E+00	-6.52108E-02	4.56249E-02	1.50823E+00	-1.06796E-01	-1.54102E-01
28	29	3.56934E+00	-1.66159E-02	3.20536E-02	1.54049E+00	-5.57894E-02	-1.69744E-01
29	30	3.60143E+00	-2.21062E-02	1.50469E-02	1.57212E+00	-4.91076E-03	-1.64259E-01
30	31	3.63158E+00	6.0985E-02	6.31238E-03	1.60327E+00	-4.58005E-02	-1.57856E-01
31	32	3.66278E+00	1.30028E-01	6.22530E-03	1.63527E+00	-4.61569E-02	-2.10575E-01
32	33	3.69405E+00	1.79230E-01	-1.66887E-02	1.66667E+00	1.46711E-01	-2.22326E-01
33	34	3.72539E+00	2.28612E-01	-3.12768E-02	1.69797E+00	1.96951E-01	-2.34168E-01
34	35	3.75568E+00	2.78165E-01	-4.41168E-02	1.72516E+00	-2.46587E-01	-2.45214E-01
35	36	3.78820E+00	3.27893E-01	-5.72621E-02	1.76042E+00	-2.56238E-01	-2.61846E-01
36	37	3.82194E+00	3.77186E-01	-7.60383E-02	1.79162E+00	-3.47540E-01	-2.66660E-01
37	38	3.85042E+00	4.26551E-01	-9.79795E-02	1.82337E+00	3.9d153E-01	-2.77138E-01
38	39	3.88127E+00	4.75331E-01	-6.72590E-02	1.85508E+00	4.40975E-01	-2.86775E-01
39	40	3.91156E+00	5.24589E-01	-1.10265E-01	1.88655E+00	4.95952E-01	-2.95715E-01
40	41	3.94251E+00	5.72625E-01	-1.22881E-01	1.91500E+00	5.51168E-01	-2.03773E-01
41	42	3.97294E+00	6.21112E-01	-1.35037E-01	1.95121E+00	6.02531E-01	-2.10827E-01
42	43	4.03228E+00	6.69426E-01	-1.46544E-01	1.98260E+00	6.54011E-01	-2.16266E-01
43	44	4.03357E+00	7.17622E-01	-1.57192E-01	2.01616E+00	7.05569E-01	-2.21038E-01
44	45	4.06233E+00	7.65767E-01	-1.66594E-01	2.04169E+00	7.57213E-01	-2.23599E-01
45	46	4.09409E+00	8.13082E-01	-1.75753E-01	2.08127E+00	8.08906E-01	-2.25300E-01
46	47	4.12642E+00	8.65183E-01	-1.83771E-01	2.11692E+00	8.62914E-01	-2.24608E-01
47	48	4.15808E+00	9.16614E-01	-1.90288E-01	2.15218E+00	9.16795E-01	-2.21628E-01
48	49	4.19152E+00	9.60222E-01	-1.98189E-01	2.18750E+00	9.75005E-01	-2.16241E-01
49	50	4.22439E+00	1.02200E+01	-2.0421E-01	2.2284E+00	1.02775E+00	-2.08315E-01
50	51	4.25752E+00	1.0721E+01	-1.99573E-01	2.25815E+00	1.06216E+00	-2.07855E-01
51	52	4.29097E+00	1.12462E+01	-1.99567E-01	2.29338E+00	1.13599E+00	-2.04696E-01
52	53	4.32477E+00	1.17756E+01	-1.97442E-01	3.2846E+00	1.16441E+00	-2.06643E-01
53	54	4.35897E+00	1.23096E+01	-1.92257E-01	3.63334E+00	1.24235E+00	-2.049569E-01
54	55	4.39361E+00	1.28488E+01	-1.85063E-01	3.9763E+00	1.29476E+00	-2.02756E-01
55	56	4.42871E+00	1.33933E+01	-1.75321E-01	4.43216E+00	1.346566E+00	-2.01093E-01
56		4.46431E+00	1.39455E+01	-1.62632E-01	4.46497E+00	1.39771E+00	-1.72984E-01
PCINT	NC	ZSEMI	XSEMI	YSEMI	ZSEMI	XSEMI	YSEMI
1	2	2.57456E+00	-1.44566E+00	-1.44527E+00	6.69683E-01		
2	3	2.57425E+00	-1.44602E+00	-1.44712E+00	6.70258E-01		
3	4	2.57356E+00	-1.44633E+00	-1.44721E+00	6.70581E-01		
4	5	2.57368E+00	-1.44654E+00	-1.44725E+00	6.70545E-01		
5	6	2.57341E+00	-1.44681E+00	-1.44723E+00	6.71358E-01		
6	7	2.572317E+00	-1.44682E+00	-1.44717E+00	6.72281E-01		
7	8	2.57295E+00	-1.44712E+00	-1.44712E+00	6.7284E-01		
8	9	2.57276E+00	-1.44721E+00	-1.44721E+00	6.73309E-01		
9	10	2.57259E+00	-1.44725E+00	-1.44725E+00	6.73848E-01		
10	11	2.57246E+00	-1.44723E+00	-1.44723E+00	6.74397E-01		
11	12	2.57235E+00	-1.44717E+00	-1.44717E+00	6.74494E-01		
12	13	2.57228E+00	-1.44706E+00	-1.44706E+00	6.75498E-01		
13	14	2.57224E+00	-1.44694E+00	-1.44694E+00	6.76139E-01		
14	15	2.57224E+00	-1.44669E+00	-1.44669E+00	6.76564E-01		
15	16	2.57227E+00	-1.44644E+00	-1.44644E+00	6.77069E-01		

PCINT	NC	ZSEMI	XSEMI	YSEMI	ZSEMI
17		2.57233E+00	-1.44615E+01	6.77548E-01	
18		2.57243E+00	-1.44582E+01	6.77546E-01	
19		2.57255E+00	-1.44545E+01	6.78407E-01	
20		2.57271E+00	-1.44506E+01	6.78777E-01	
21		2.57290E+00	-1.44464E+01	6.79103E-01	
22		2.57311E+00	-1.44420E+01	6.79380E-01	
23		2.57335E+00	-1.44374E+01	6.79606E-01	
24		2.57361E+00	-1.44327E+01	6.79778E-01	
25		2.57389E+00	-1.44279E+01	6.79894E-01	
26		2.57418E+00	-1.44231E+01	6.79953E-01	
27		2.57449E+00	-1.44184E+01	6.79954E-01	
28		2.57481E+00	-1.44137E+01	6.79892E-01	
29		2.57513E+00	-1.44092E+01	6.79784E-01	
30		2.57545E+00	-1.44049E+01	6.79615E-01	
31		2.57578E+00	-1.44008E+01	6.79391E-01	

BLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS

RADIUS	SECTION ANGLE	STATION 3	NUMBER OF FACII= 6
		LEAN ANGLE	BLADE BLOCKAGE
3.03363	-34.5568	-5.7373	.1506
4.36966	-35.5746	-2.4342	.1002
5.24156	-45.2380	-2.5752	.0763
6.49755	-51.2217	-1.0544	.0551
7.80911	-57.5491	2.4170	.0415
8.50660	-60.9548	2.7736	.0373

RADIUS	SECTION ANGLE	STATION 4	NUMBER OF FACII= 6
		LEAN ANGLE	BLADE BLOCKAGE
3.3897	-25.0291	-5.4105	.1931
4.3344	-31.0055	-2.1165	.1407
5.4154	-38.8175	-3.6777	.1673
6.5824	-47.5182	-3.3044	.0795
7.8307	-55.7777	-4.4144	.0441
8.5000	-59.8318	.6624	.0595

RADIUS	SECTION ANGLE	STATION 5	NUMBER OF FACII= 6
		LEAN ANGLE	BLADE BLOCKAGE
3.7385	-12.8974	-4.6022	.1783
4.5798	-20.6393	1.8574	.1366
5.5662	-32.2241	-5.642	.1576
6.6591	-43.3122	-3.275	.0847
7.8455	-53.2632	-3.0192	.0707
8.5005	-58.3035	-4.1039	.0674

RADIUS	SECTION ANGLE	STATION 6	NUMBER OF FACII= 6
		LEAN ANGLE	BLADE BLOCKAGE
4.0884	-6.6516	3.8432	.1186
4.8259	-8.6767	9.3017	.0958
5.7147	-23.7341	6.1020	.0751
6.7242	-38.5832	-1.5136	.0668
7.6575	-40.1964	-4.9335	.0602
8.5360	-56.4561	-7.4341	.0613

STATION	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
4.4612	38.0404	21.8805	.0108	-.0386
5.0795	11.3831	23.1255	.0143	-.0924
5.8623	-14.4548	17.0305	.0034	-.1486
6.7858	-33.9363	5.1628	.0059	-.1756
7.8716	-47.4131	-5.0787	.0046	-.1770
8.5000	-53.4651	-11.9278	.0076	-.1656

PLACE SURFACE GEOMETRY IN CARTESIAN COORDINATES AT SPECIFIED VALUES OF 'Z'

SECTION NUHEE 1 25 = 2.5000

SECTION PROPERTIES	SECTION AREA	YEAR	YEAR
LOCATION OF CENTROID RELATIVE TO STACK AXIS		= -6.1846E-02	= 6.9764E-02
SECOND MOMENTS OF AREA ABOUT CENTROID	IX = 1.3702E-02 IY = 1.5176E-01 IXY = -6.5456E-02		
PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID	IFX = 1.3204E-02 IFY = 1.5234E-01	(AT -3.69 DEGREES TO 'X' AXIS)	(AT -3.69 DEGREES TO 'Y' AXIS)
TORSIONAL CONSTANT	= 5.2463E-02		

SECTION COORDINATES

POINT NO	X <sub>S</sub>	Y <sub>S</sub>	X <sub>F</sub>	Y <sub>F</sub>
1	-1.44091E+00	6.62066E-01	-1.44511E+00	6.52778E-01
2	-1.36221E+00	6.23323E-01	-1.39263E+00	6.03771E-01
3	-1.32456E+00	5.85667E-01	-1.34005E+00	5.55753E-01
4	-1.26734E+00	5.49061E-01	-1.28734E+00	5.06661E-01
5	-1.29645E+00	5.12470E-01	-1.23447E+00	4.24945E-01
6	-1.15234E+00	4.78814E-01	-1.18142E+00	4.17246E-01
7	-1.05513E+00	4.45071E-01	-1.12618E+00	3.72926E-01
8	-1.02801E+00	4.12206E-01	-1.07475E+00	3.29548E-01
9	-9.80915E-01	3.80153E-01	-1.02110E+00	2.87040E-01
10	-9.24008E-01	3.488053E-01	-9.67243E-01	2.45386E-01
11	-8.67123E-01	3.162240E-01	-9.13172E-01	2.04565E-01
12	-8.10307E-01	2.89257E-01	-8.58895E-01	1.64563E-01
13	-7.61139E-01	2.61341E-01	-8.11443E-01	1.30679E-01
14	-7.12531E-01	2.38813E-01	-7.64062E-01	9.76913E-02
15	-6.64526E-01	2.15356E-01	-7.16732E-01	6.56798E-02
16	-6.17158E-01	1.92875E-01	-6.66433E-01	3.47820E-02
17	-5.70473E-01	1.71620E-01	-6.22150E-01	2.21168E-03
18	-5.24507E-01	1.51854E-01	-5.24863E-01	2.28647E-02
19	-4.75303E-01	1.33574E-01	-5.27566E-01	4.94102E-02
20	-4.34912E-01	1.16868E-01	-4.80238E-01	-7.41219E-02
21	-3.91358E-01	1.02111E-01	-4.32876E-01	-9.67267E-02
22	-3.42707E-01	8.96025E-02	-3.85448E-01	-1.16884E-01
23	-3.05999E-01	7.94374E-02	-3.37576E-01	-1.34486E-01
24	-2.64881E-01	7.09582E-02	-2.85695E-01	-1.49950E-01
25	-2.25028E-01	6.47642E-02	-2.41639E-01	-1.62525E-01
26	-1.81382E-01	6.04421E-02	-1.94489E-01	-1.72093E-01
27	-1.35893E-01	5.78008E-02	-1.47741E-01	-1.79023E-01
28	-9.85226E-02	5.69800E-02	-1.01673E-01	-1.83634E-01
29	-5.712266E-02	5.72920E-02	-5.63666E-02	-1.66170E-01
30	-1.55913C-02	5.855733E-02	-1.18569E-02	-1.86619E-01
31	2.52156E-02	6.06622E-02	3.16699E-02	-1.05335E-01
32	6.6101CE-02	6.329303E-02	7.42715E-02	-1.82722E-01
33	1.07567E-01	6.59070E-02	1.15659E-01	-1.79194E-01
34	1.46727E-01	6.83091E-02	1.56375E-01	-1.74940E-01

FCINT NO	X S	Y S	X P	Y P
25	1.87827E-01	7.07226E-02	1.94538E-01	6.9955E-01
36	2.26936E-01	7.29277E-02	2.32728E-01	6.64692E-01
37	2.63943E-01	7.50131E-02	2.66747E-01	5.8903E-01
38	2.96151E-01	7.73488E-02	3.06779E-01	5.265E-01
39	3.34271E-01	8.03610E-02	3.43413E-01	4.4451E-01
40	3.66422E-01	8.43596E-02	3.75642E-01	3.5235E-01
41	4.01635E-01	8.92567E-02	4.15442E-01	2.4240E-01
42	4.33945E-01	9.57912E-02	4.50406E-01	1.107355E-01
43	4.65452E-01	1.04638E-01	4.85701E-01	9.43730E-02
44	4.96101E-01	1.15936E-01	5.020122E-01	7.52074E-02
45	5.26081E-01	1.29543E-01	5.54118E-01	5.25993E-02
46	5.65661E-01	1.47120E-01	5.98442E-01	3.0496E-02
47	6.05137E-01	1.69887E-01	6.42467E-01	1.30288E-02
48	6.45675E-01	1.98623E-01	6.85514E-01	6.2132E-02
49	6.84044E-01	2.33723E-01	7.25558E-01	1.07248E-01
50	7.22652E-01	2.75563E-01	7.70158E-01	1.66419E-01
51	7.63492E-01	3.25882E-01	8.10429E-01	2.34813E-01
52	8.03664E-01	3.86627E-01	8.45057E-01	3.14310E-01
53	8.44294E-01	4.58989E-01	8.85717E-01	4.05505E-01
54	8.85492E-01	5.44508E-01	9.20250E-01	5.09385E-01
55	9.27413E-01	6.45143E-01	9.51715E-01	6.27039E-01
56	9.70161E-01	7.63431E-01	9.80219E-01	7.59971E-01
FCINT NO	X SEMI	Y SEMI	X SEMI	Y SEMI
1	-1.44511E+00	6.52778E-01	6.53122E-01	6.53122E-01
2	-1.44549E+00	6.53514E-01	6.53940E-01	6.53940E-01
3	-1.44616E+00	6.54420E-01	6.54925E-01	6.54925E-01
4	-1.44643E+00	6.55458E-01	6.55832E-01	6.55832E-01
5	-1.44666E+00	6.56012E-01	6.56588E-01	6.56588E-01
6	-1.44699E+00	6.56581E-01	6.59440E-01	6.59440E-01
7	-1.44712E+00	6.57160E-01	6.59971E-01	6.59971E-01
8	-1.44714E+00	6.57742E-01	6.60320E-01	6.60320E-01
9	-1.44685E+00	6.58388E-01	6.61372E-01	6.61372E-01
10	-1.44698E+00	6.59440E-01	6.61595E-01	6.61595E-01
11	-1.44712E+00	6.60320E-01	6.62099E-01	6.62099E-01
12	-1.44705E+00	6.60942E-01	6.62307E-01	6.62307E-01
13	-1.44695E+00	6.60888E-01	6.62621E-01	6.62621E-01
14	-1.44679E+00	6.61372E-01	6.62798E-01	6.62798E-01
15	-1.44652E+00	6.61595E-01	6.62916E-01	6.62916E-01
16	-1.44634E+00	6.60320E-01	6.62973E-01	6.62973E-01
17	-1.44634E+00	6.60942E-01	6.62970E-01	6.62970E-01
18	-1.44572E+00	6.61372E-01	6.64177E+00	6.62906E-01
19	-1.44537E+00	6.61595E-01	6.64136E+00	6.62782E-01
20	-1.44498E+00	6.62099E-01	6.64272E+00	6.62599E-01
21	-1.44458E+00	6.62307E-01	6.64224E+00	6.62360E-01
22	-1.44412E+00	6.62621E-01	6.64417E+00	6.62066E-01
23	-1.44366E+00	6.63172E-01	6.64413E+00	6.62782E-01
24	-1.44319E+00	6.63916E-01	6.64408E+00	6.62599E-01
25	-1.44272E+00	6.62973E-01	6.64442E+00	6.62360E-01
26	-1.44224E+00	6.62970E-01	6.64401E+00	6.62066E-01
27	-1.44177E+00	6.62906E-01	6.64001E+00	6.62066E-01
28	-1.44136E+00	6.62798E-01	6.64001E+00	6.62066E-01
29	-1.44085E+00	6.62916E-01	6.64001E+00	6.62066E-01
30	-1.44042E+00	6.62973E-01	6.64001E+00	6.62066E-01
31	-1.44001E+00	6.62970E-01	6.64001E+00	6.62066E-01

## SECTION VII

### COMPUTER PROGRAM DETAILS

#### 1. IMPLEMENTATION OF THE COMPUTER PROGRAM

The program is written in FORTRAN IV and was developed on a CDC 6000 Series System, incorporating the version 3.3 SCOPE Operating System. When loaded into core, the program (and resident system) occupies about 32K of storage, so that the program will probably not be usable without modification on a relatively small computer. Apart from this limitation, the program should be compatible with the majority of modern computing systems. The program consists of a main program, and Subroutines BQ, CQ, D1, EQ, and FQ. The six decks have been given the identifiers A, B, C, D, E, and F, respectively. Listings of the decks are shown below, and the deck set-up required for the CDC 6000 Series System is also presented.

The program uses three numerical system units for its input and output routines. Input is drawn from the card unit via READ statements referring to Unit LOG 1; output is sent to the line printer by WRITE statements referring to Unit LOG 2; and punched output is produced via WRITE statements referenced to Unit LOG 3. Units LOG 1, LOG 2, and LOG 3 are set equal to 5, 6, and 7, respectively, on cards A130-140 in the FORTRAN programming. On the CDC 6000 Series System, the "PROGRAM" card must also establish the input and output linkages. On other computing systems, the "PROGRAM" card may not be required, and the input-output files may be established via control cards.

The program as presented herein utilizes an on-line precision plotting capability available at the program development site. Calls to four subroutines not included in the deck are included in the program. These calls are executed only if precision plots are specified in the input data, and the entry points expressed are part of standard CALCOMP software normally supplied to users of CALCOMP precision plotting equipment. The various call statements used in the program are explained below, to facilitate modification should the need arise.

CALL PLOT (XPLOT, YPLOT, N)

The majority of plotting is done using this form of call. The parameters XPLOT and YPLOT are the "x" and "y" coordinates (in inches) on the paper to which the pen is being directed. The parameter N indicates pen up or down,  $|N| = 3$  or  $|N| = 2$ , respectively, and will cause XPLOT or YPLOT to be assigned as the origin for further coordinates if N is negative.

**CALL SYMBOL (X, Y, H, TEXT, THETA, N)**

This call is used to title the plots. The parameters X and Y are the coordinates (in inches) of the lower left hand corner of the first character, H is the character height (in inches), TEXT is the character to be printed, THETA is the angle of the lettering with respect to the "x" axis and N is the total number of characters to be printed.

**CALL NUMBER (X, Y, H, F, THETA, N)**

This call causes the printing of the number F. The parameters X, Y, H, and THETA are used as for CALL SYMBOL. The parameter N indicates the number of digits following the decimal point if positive, or truncation to an integer if equal to -1.

**CALL PLOTE**

This call terminates the tape.

In the event the program is used on a computing system which does not include CALCOMP software, and the operating system will not execute a program with unsatisfied external references, dummy entry points may be supplied by adding to the deck a subroutine such as the following:

**SUBROUTINE PLOT**

A = A

ENTRY SYMBOL

ENTRY NUMBER

ENTRY PLOTE

RETURN

END

## **2. DECK SETUP FOR CDC 6000 SERIES SYSTEM**

The deck setup required to run the program on a CDC 6000 Series System incorporating the SCOPE 3.3 Operating System is shown below. Production runs of the program would usually employ relocatable binary forms of the routines produced from the source decks to avoid having to compile the FORTRAN for each run and the waste of associated computer resources.

JOB Identification, etc.

FTN.

LGO.

7/8/9 End of Record

SOURCE DECK A

SOURCE DECK B

SOURCE DECK C

SOURCE DECK D

SOURCE DECK E

SOURCE DECK F

7/8/9 End of Record

DATA DECK

6/7/8/9 End of Job

### 3. FORTRAN PROGRAM LISTING

A listing of the FORTRAN program appears on the following pages with each subroutine started on a new page.

```

PROGRAM ARBITR(INPUT,OUTPUT,PUNCH,PLOT,TAPE5=INPUT,TAPE6=OUTPUT,
1 TAPE7=PUNCH)
      DIMENSION AIRANG(10,15), YPFME(81), SL(82), YU(81), BETNET(10),
1(10,5), DEVCRV(10,5), RADEV(5), RINC(15), XINC(15), EXB(15),
2, DEVRAD(10), LL(10), CELDEV(15), F137E(8), F137S(5), F161D(8,5),
3 F195M(8,2), F164XB(8), F172K(7), F142TC(7), NPTS(15), YPRNE(81),
4 YA(15), YB(15), YC(15), YE(15), NOINF(51), SOFARR(51), FDMIN(51),
COMMCN EPZ(100,3), R(10,15), ZOUT(15), SS(100), X(100), YFRINE(100), YSC(
115,81), YP(15,81), XP(15,81), XS(15,81), YSEM(15,31), XSEM(15,31), ZS(
215,81), ZP(15,81), ZSEMI(15,31), TITLE(8), XHERE(10), XTEMP(100), RAD(10
30), TEMP1(15), TEMP2(15), TEP(15), TEMP(15), ZR(15), ZZ(15), RLE(15), T
4C(15), TE(15), SDIVR(15), CELX(15), OELY(15), XSTA(15,10), RSTA(15,10), K
SFIS(15), SIGMA(100), TANFHI(10,15), ZCAMB(15,10), YCAMB(15,10), IFANGS(
610), THETA(15,10), ALFH(15,10)
      REAL IX,IY,IXY,IPX,IPY,IXH,IYN,IXYN,IXO,IYO
      DATA F137B/0.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0/
      DATA F137S/0.4,0.8,1.2,1.6,2.0/
      DATA F142TC/0.0,0.0,0.0,0.04,0.06,0.08,0.10,0.12/
      DATA F161D/0.0,0.0,0.0,0.09,0.0,0.17,0.29,0.42,0.59,0.79,1.05,0.0,0.12,0.30,0
1.51,0.75,1.05,1.47,2.07,0.0,0.16,0.33,0.61,0.95,1.42,2.12,3.07,0.0
2.0,1.17,0.40,0.72,1.11,1.71,2.62,3.95,0.0,0.2,0.44,0.78,1.21,1.90,3.
3.01,4.75/
      DATA F195M/0.17,0.173,0.179,0.189,0.206,0.232,0.269,0.310,0.25,0.2
1.55,0.261,0.268,0.278,0.292,0.312,0.342/
      DATA F164XE/0.965,0.945,0.921,0.890,0.850,0.782,0.675,0.550/
      DATA F172K/0.0,0.161,0.331,0.521,0.74,1.0,1.300/
      LOG1=5
      LOG2=6
      LOG3=7
      PI=3.1415926536
      C1=180.0/PI
      READ (LCG1,5) TITLE
      FORMAT (7A10,A2)
      WRITE (LOG2,10) TITLE
      5
      FORMAT (1H1,38X,44HUSAF - ARL (LF) ARBITRARY CAMBER LINE PROGRAM,/,A
139X,44(1H*)//,10X,5HTITLE,25X,1H=,7A10,A2)
      READ (LCG1,15) NLINES,NSTNS,NZ,NSPEC,ISEGFT,NBLADE,ISTAK,IPUNCH,IF
      1PLOT,IPRINT
      10
      FORMAT (12I3)
      WRITE (LCG2,20) NLINES,NSTNS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,I
      1FFLCT,IFRINT
      15

```

```

26   FORMAT (10X,24HNUMBER OF STREAMSURFACES,6X,1H=,I3,/ ,10X,18HNUMBER
1OF STATIONS,12X,1H=,I3,/ ,10X,27HNUMBER CF CCNSTANT-Z PLANES,3X,1H=
2,I3,/ ,10X,27HNUMBER OF ELADE DATA PCINTS,3X,1H=,I3,/ ,10X,31HNUMBER
3 OF FCINTS PER SEGMENT =,I3,/ ,10X,29+NUMBER OF BLADES IN BLADE RO
4W,1X,1H=,I3,/ ,10X,5HISTAK,25X,1H=,I3,/ ,10X,6HIPUNCH,24X,1H=,I3,/ ,1
50X,6HIFPLOT,24X,1H=,I3,/ ,10X,6HIPRINT,24X,1H=,I3,/ ,1
A 205
A 210
A 215
A 220
A 225
A 230
A 235
A 240
A 245
A 250
A 255
A 260
A 265
A 270
A 275
A 280
A 285
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A 360
A 365
A 370
A 375
A 380
A 385
A 390
A 395
A 400

FORMAT (/ ,10X,6HZINNER,24X,1H=,F8.4/,10X,6HZCUTER,24X,1H=,F8.4/,2
110X,5HSIZE,25X,1H=,F8.4,/,10X,6HSTACKX,24X,1H=,F8.4,/,10X,6HPLTSZ
2E,24X,1H=,F8.4,/,2CX)
READ (LCG1,15) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
WRITE (LCG2,35) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
FORMAT (10X,27HLEADING EDGE STATION NMBR,3X,1H=,I3,/ ,10X,28HTRAI
1LING EDGE STATION NMBR,2X,1H=,I3,/ ,10X-26HRADI SPECIFYING DEVIAT
ION,4X,1H=,I3,/ ,10X,26-RADI SPECIFYING INCIDENCE,4X,1H=,I3/10X,2
37HSENSE OF ROTATION IN CICATR,3X,1H=,I3,/ ,10X,27HDEVIATION CALCULAT
ION INDEX,3X,1H=,I3,/ ,10X,28HNUMBER OF INITIAL S/R TRIALS,2X,1H=,
5I3,/ ,2X)
READ (LCG1,25) XKSHEF,SCLTOL
WRITE (LCG2,40) XKSHEF,SOLTCL
FORMAT (10X,12HSHAPE FACTCR,18X,1H=,F8.4,/,10X,18HSOLIDITY TCLRAN
1CE,12X,1H=,F8.4,/,2X)
DO 55 K=1,NRADEV
READ (LOG1,15) NPTS(K)
READ (LOG1,25) RADEV(K)
WRITE (LCG2,45) K,NPTS(K),RADEV(K)
FORMAT (5X,16HDEVIATION CURVE ,12,5X,18HNUMBER OF PCINTS =,I2,5X,6
1RHADIUS =,F8.4,/,2X)
NPT=NPTS(K)
READ (LCG1,50) (SM(j,k),DEVCRV(j,k),J=1,NFT)
FORMAT (2F12.0)
55 WRITE (LOG2,60) (J,SN(j,k),DEVCRV(j,k),J=1,NPT)
66 FORMAT (10X,5HPCINT,5X,22HNCRMALIZED REPLICATIONAL,5X,20HNCRMALIZED
1DEVIATION,/,28X,5HCHORD,18X,12HDISTRIBUTION,/,111X,I2,14X,F6.4,20X
2,F6.4)
READ (LCG1,65) (RINC(j),XINC(j),DELDEV(j),J=1,NINC)
FORMAT (3F12.0)
65 WRITE (LCG2,70) (RINC(j),XINC(j),DELDEV(j),J=1,NINC)

```

```

70   FORMAT (2X,/,5X,42HINCIDENCE AND EXTRA DEVIATION DISTRIBUTION,/,//,      A 405
     110X,12HINLET RADIUS,4X,5HINCIDENCE,4X,15HEXTRA DEVIATION,//(F19.4,      A 410
     2F14.3,F15.3),      A 415
     LNCT=3      A 420
     LNCT=3      A 425
     WRITE (LOG2,75)      A 430
75   FORMAT (1H1,/,20X,36HSTREAMSURFACE GEOMETRY SPECIFICATION)      A 435
     DO 120 I=1,NSTNS      A 440
     READ (LCG1,15) KPTS(I),IFANGS(I),LOG8      A 445
     IF (LOG8.EQ.0) LOG8=5      A 450
     KPT=KPTS(I)
     READ (LCG1,50) XSTA(K,I),RSTA(K,I),K=1,KFT)      A 455
     IF (KPTS(I).GE.2) GO TO 80      A 460
     KPTS(I)=2      A 465
     XSTA(2,I)=XSTA(1,I)
     RSTA(2,I)=RSTA(1,I)+1.0      A 470
     READ (LCG8,50) (R(I,J),AIRANG(I,J),J=1,NLINES)      A 475
     IDUM=KPTS(I)
     IDUM=NLINES.GT.IDUM) IDUM=NLINES      A 480
     IF (NLINES.LE.54-NLINES) GO TO 90      A 490
     WRITE (LOG2,85)
     FORMAT (1H1)
     LNCT=1      A 505
     LNCT=LNCT+IDUM+6      A 510
     LNCT=LNCT+3      A 515
     WRITE (LCG2,95) I,KFTS(I),I,IFANGS(I)
     FORMAT (2X,/,10X,17HCONFIGURING STATION,I3,5X,28HNUMBER OF DESCRIBIN      A 520
     16 PCINTS=,I3,6X,7HIFANGS(,I2,2H)=,I3,/6X,11HDESCRIPTION,9X,10HSTR      A 525
     2EAMLINE,5X,SHRADII,11X,5HHAIR ANGLE,) ,EX,1RX,9X,1HR,1IX,6HNUMBER,/,      A 530
     3,2X)      A 535
     DO 100 K=1, IDUM      A 540
     IF (K.LE.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,105) XSTACK(K,I),RSTA(      A 545
     1K,I),K,R(I,K),AIRANG(I,K)
     IF (K.LE.KPTS(I).AND.K.GT.NLINES) WRITE (LOG2,110) XSTACK(K,I),RSTA(      A 550
     1K,I)
     IF (K.GT.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,115) K,R(I,K),AIRANG      A 555
     1(I,K)
     100 CONTINUE      A 560
     105 FORMAT (3X,F8.4,2X,F8.4,8X,12,9X,F8.4,9X,F8.4)      A 565
     110 FORMAT (3X,F8.4,2X,F8.4)      A 570
     115 FORMAT (29X,12,9X,F8.4,9X,F8.4)      A 575
     120 CONTINUE      A 580

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IF (LNCT.LE.54-NSPEC) GC TO 125
WRITE (LOG2,85)
LNCT=1
LNCT=LNCT+NSPEC+6
READ (LCC1,130) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J)),
122(J),SDIVR(J),CELY(J),DELY(J),J=1,NSPEC)
130 FORMAT (6F12.0)
      WRITE (LCG2,135) (ZF(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J),
1,ZZ(J),SDIVR(J),DELY(J),J=1,NSPEC)
135 FORMAT (2X,/20X,30SECTION GEOMETRY SPECIFICATION,/,10HSTREA
1MLINE,2X,5HSLD,5X,6HIN.CEL,4X,6HCONSID,4X,6HNC.ALD,3X,48HLE RADI
2US MAX THICK TE THICK POINT OF START VAL,3X,7H STACK,3X,7H STAC
3K,/,11X,6HNUMBER,5X,5HCL FT,5X,5HS/R0,3X,1SHLE RD CRV INFL. PTS,3
4X,6H/CHORD,4X,6H/CHCRD,3X,8H/2*CHORD,2X,18HMAX THICK OF S/R ,4X,6
5HOFFSET,4X,6HcffSET,/,10X,F7.2,3X,F8.3,F10.3,2F10.4,3F10.5,2F10.
64,F1.6,F10.6)
      IF (IFFPLOT.EQ.4) CALL PLOT (0.0,-PLTSZE,-3)
      IF (IFFPLOT.EQ.0.0R.IFPLOT.EQ.4) GO TO 140
IKOUM=0
      IF ((AIRANG(IRLE,1)-AIRANG(IRTE,1)).LT.0.) IKOUM=1
      IF (IFFPLOT.EQ.1.0R.IFPLOT.EQ.3) CALL FQ (ISTAK,PLTSZE,1,TITLE,IKOU
1H,IFFPLOT)
140 DO 465 J=1,NLINES
      DO 145 I=IRLE,IRTE
      KPT=KPTS(I)
      CALL 01 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(IRLE)
      X(100)=XHERE(IRTE)
      AX=(X(100)-X(1))/99.0
      DO 150 I=2,99
      X(I)=X(I-1)+AX
      ICORIT=IRTE-IRLE+1
      CALL CQ (XHERE(IRLE),R(IRLE,J),ICORIT,X,XGUM,YPRIME,100,1)
      SS(1)=0.0
      DO 155 I=2,100
      SS(I)=SS(I-1)+AX*SQRT (1.0+((YPRIME(I)*YPRIME(I-1))/Z.0)**2)
      XJ=J
      CALL 01 (ZR,RLE,NSPEC,XJ,YZERO,1,0)
      CALL 01 (ZR,TC,NSPEC,XJ,T1,0)
      CALL 01 (ZR,TE,NSPEC,XJ,YCNE,1,0)

```

```

CALL D1 (ZR,DELLX,NSFEC,XJ,XCEL,1,0) A 805
CALL D1 (ZR,DELY,NSFEC,XJ,YCEL,1,0) A 810
CALL D1 (ZR,ZZ,NSPEC,XJ,Z,1,0) A 815
CALL D1 (ZR,YA,NSPEC,XJ,SSOLID,1,0) A 820
CALL D1 (ZR,SDIVR,NSPEC,XJ,SDR,1,0) A 825
CALL D1 (ZR,YB,NSPEC,XJ,DELSDR,1,0) A 830
CALL D1 (ZR,YC,NSPEC,XJ,RELEMN,1,0) A 835
CALL D1 (ZR,YE,NSPEC,XJ,ACCIPP,1,0) A 840
I=IPASS-1 A 845
LN=0 A 850
IJK=-1 A 855
PRNT=0. A 860
XSIGN=NSIGN A 865
STAGER=(AIRANG(IRLE,J)+AIRANG(IRTE,J))/2. A 870
RINSCL=(R(IRLE,J)+R(IRTE,J))/2. A 875
SUR1=S0R A 880
CHORC=SS(100)/COS(STAGER/C1) A 885
IF (IPRINT.NE.0.AND.IPRINT.NE.-1) GO TO 170 A 890
IF (IJK.EQ.3) WRITE (LC62,165) S0R A 895
FORMAT (1H1,9X,15HOFTIMAL SECTION,/1CX,15(1H*),//,10X,11HFFINAL S/
1R =,F8.4,/,10X,23HITERATIONS ON SOLICITY ) A 900
SOLID=CHORD/RINSOL/2./PI*FLCAT(\BLADE)
CALL D1 (RING,XING,NINC,R(IRLE,J),TEMF2,1,0) A 910
CALL D1 (RING,DELDEV,NINC,R(IRLE,J),TEMF3,1,0) A 915
BETNET(1)=AIRANG(IRLE,J)-XSIGN*TEMF2(1)
BETS=AIRANG(IRLE,J)*XSIGN A 920
DO 175 K=1,5 A 925
CALL D1 (F137B,F161D(1,K),8,BETS,EXB(K),1,0) A 930
CALL D1 (F137E,F195W(1,IFCA),8,BETS,XYS,1,0) A 935
CALL D1 (F137B,F164YB,S,BETS,XTEMP,1,E) A 940
CALL D1 (ZR,TC,NSPEC,XJ,X1,1,0) A 945
CALL D1 (F142T0,F172K,7,X1,XKDT,1,0) A 950
BETS=BETNET(1)*XSIGN A 955
NN=0 A 960
NN=NN+1 A 965
IF (NN.GT.20) GC TO 700 A 970
CALL C1 (F137S,EXB,5,SLIC,CO,1,1) A 975
XMH=XHS/SOLID**XTENF(1) A 980
DEV=(00*XKDT*XKSHPE*XHH)*(EEETS-XSIGN*AIRANG(IRTE,J))+TEMF3(1)*1.0/ A 985
1(1.-XHM) A 990
A 995
A 1000

```

```

185 IF ( IJK.EQ.3 .AND. IPFINT.NE.2 ) WRITE (1062,185) NN,DEV,SCLIC
      FORMAT (33X,10HITERATION ,I2,3X,11HDEVIATION =,F7.3,3X,10HSOLIDITY
1     =>F7.4)
      HN=IRTE-IRLE+1
      BETNET(MN)=AIRANG(IRLE,J)-DEV*XSIGN
      S1(1)=0.
      DO 205 I=1,NSTNS
        IF ( I-IRLE) 205,205,190
        IF ( IRTE-I) 205,205,195
190       L=I-IRLE+1
195       CALL D1 (X,SS,100,XPERE(I),S1(L),1,1)
      S1(L)=S1(L)/SS(100)
      DO 200 K=1,NRADEV
200       CALL D1 (SH(1,K),DEVCRV(1,K),NPIS(K),S1(L),DEVRAD(K),1,0)
      CALL D1 (RADEV,DEVRAD,NRACEV,R(IRTE,J),DEVPCF,1,0)
      BETNET(L)=AIRANG(I,J)-DEV*DEVPCF*XSIGN
      CONTINUE
      S1(MN)=1.
      YP1=TAN(BETNET(1)/C1)
      YMPRME(1)=YF1
      YU(1)=0.
      IPPOINT=1
      SU(1)=0.
      Y1=0.
      YPP1=SDR/2.*PI/R(IRLE,J)*FLOAT(NBLADE)*(1.+YP1)**(1.5)
      YPPME(1)=YFF1
      IF ( YPF1.NE.0.) GO 10 210
      YPRIME(1)=1000.
      GC IC 215
      CONTINUE
      YPRIME(1)=(1.+YMPRME(1))*YMPRME(1)*((1.-5)/YFPME(1))
210      CONTINUE
      S1=0.
      S12=0.
      LL(1)=0
      DO 230 K=2,MN
230      YP2=TAN(BETNET(K)/C1)
      LL(K)=0
      S2=S1(K)
      S22=S2*S2

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A1400

A= (YF2-YP1-YPF1*(S2-S11))/3.0/(S22-S12-2.*S11*(S2-S11))
B=(YPP1-6.*A*S11)/2.
C=YP1-3.*A*S12-2.*B*S11
D=Y1-A*S12*S11-B*S12-C*S11
SDIFF=(S2-S11)/FLOAT(ISEGFT-1)
KL=IFOINT+1
KJ=IFOINT+ISEGFT-1
DO 225 L=KL,KJ
   SU(L)=SU(L-1)+SDIFF
   YU(L)=D+SU(L)*(C+SU(L)*(B+A*SU(L)))
   YMPE(L)=C+SU(L)*(E*2.+A*3.*SU(L))
   YPPME(L)=E.*A*SU(L)+2.*E
   IF (YPPME(L).EQ.0.) YPRIME(L)=1000.
   IF (YPPME(L).EQ.0.) GO TO 225
   YPRIME(L)=(1.+YMPE(L)*YPRME(L))**(1.E) /YFPME(L)
   SLPE=ABS(YPPME(L)-YFPME(L-1))
   IF (SLPE.GE.ABS(YPPME(L)).AND.SLPE.GE.ABS(YFPME(L-1))) GO TO 220
   GO TO 225
LL(K)=L
220  CONTINUE
IPOINT=KJ
Y1=YU(IPOINT)
YPP1=YPPME(KJ)
S11=S2
S12=S22
YF1=YF2
IS=0
DO 235 K=1,MN
   IF (LL(K).NE.0) IS=IS+1
230  CONTINUE
CHORD1=SQRT(YU(IPOINT)**2+1.)*SS(10.0)
CALL D1 (SU,YU,IPOINT,SSOLID,YSOLID,1,1)
CHORC=SQRT ((SU(IPOINT)-SSCLID)**2+(YU(IPOINT)-YSOLID)**2)*SS(100)
SOLID1=CHORD/RINSL/2./FI*FLOAT(NBLADE)
CIFF=SCOLID-SOLID1
IF (ABS(DIFF).LT.SOLTOL*SCLID) GO TO 240
GO TO 180
IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SOLID1
IF (IJK.EQ.3) GO TO 305

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LHN=LHN+1
NOINF(LHN)=IS
SDRARR(LHN)=SDR
RDMIN(LHN)=1000.
00 245 L=1,IPCINT
IF (L.EQ.1.AND.ROLEMN.EQ.1.0) GO TO 245
IF (ABS(YPRIME(L)).LT.RCHMIN(LNN)) RDMIN(LNN)=ABS(YPRIME(L))
245 CONTINUE
IF (LMN.LE.IJ.AND.IJK.LE.0) GO TO 160
IF (LMN.GT.IJ.AND.IJK.LE.0) GO TO 250
IF (LMN.GT.19) GO TC 25G
GO TC 160
IF (LMN.EQ.20.OR.LMN.EQ.IPASS) IJK=IJK+1
IF (IJK.EQ.20.IJK.EQ.3) GC TO 290
NMNINF=20
DC 255 LHN=1,IPASS
IF (NOINF(LMN).LT.NMNINF) IFIRST=LHN
IF (NCINF(LMN).LT.NMNINF) NMNINF=NOINF(LHN)
255 CONTINUE
IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TC 275
WRITE (LCG2,85)
IF (FLOAT(NMNINF).GE.(ACCIFF+1.0).AND.IPRINT.NE.2) WRITE (LOG2,260)
1, FORMAT (74H NOTE THAT THE MINIMUM NUMBER OF INFLECTION POINTS IS G
1 GREATER THAN DESIRED,/2X)
INDEX=IJK+1
260 INDEX,J,INDEX,SDR1,DELSDR
WRITE (LOG2,265) J,INDEX,SDR1,DELSDR
FORMAT (5X,14HSTREASURFACE',12,/10X,10HITERATION ,12,/10X,12(1H*
1),//,10X,14HINITIAL S/R =,F8.4,10X,17HINCREMENTAL S/R =,F8.4,/,1
25X,8HFASS NC.,5X,21HNO. OF INFLECTION PTS,5X,24HMIN. RADIUS CF CUR
3YATURE,/2X)
FORMAT (18X,12,18X,12,22X,F8.3)
270 ILAST=0
275 FORMAT (18X,12,18X,12,22X,F8.3)
00 280 LHN=IFIRST,IPASS
IF (NCINF(LHN).GT.NMNINF) ILAST=LHN
IF (NCINF(LHN).GT.NMNINF) GC TO 285
280 CONTINUE
ILAST=IPASS

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A1795
A1800

285   IF (IJK.EQ.0) IFIRST=IFIRST-1
      IF (IFIRST.EQ.0) IFIRST=1
      IF (IFIRST.EQ.IPASS) IFIRST=IJ
      IF (IJK.EQ.1.AND.NCINF(IFASS).GT.NMAINF) ILAST=ILAST-1
      IF (ILAST.EQ.IFIRST) ILAST=ILAST+1
      IF (ILAST.EQ.(IFASS+1).CR.ILAST.EQ.0) ILAST=IFASS
      IF (IJK.EQ.0) LJ=IPASS-1
      IF (IJK.EQ.1) LJ=19
      DELSCR=(SDRARR(ILAST)-SCRARR(IFIRST))/FLOAT(LJ)
      SDR=SDRARR(IFIRST)
      SDR1=SDR
      LMN=0
      GO TC 160
      RADX=X=0.
      DO 295 L=1,20
      IF (RDMIN(L).GT.RADX.AND.NCINF(L).EQ.NNNINF) LMN=L
      IF (RDMIN(L).GT.RADX.AND.NCINF(L).EQ.NMNINF) RADX=RDMIN(L)
      CONTINUE
      IF (LMN.EQ.1.AND.IPRINT.NE.2) WRITE (LOG2,30)
      IF (LMN.EQ.20.AND.IPRINT.NE.2) WRITE (LCG2,300)
      FORMAT (/10IH THE MAXIMUM VALUE OF THE MINIMUM RADIUS CF CURVATUR
      1E OCCURS AT AN END POINT OF THE PRESENT S/R RANGE)
      IF (IJK.EG.3) SDR=SCRARR(LMN)
      IF (IJK.EQ.3) PRNT=1.
      IF (IJK.EG.3) GC TO 160
      SDR=SDRARR(LMN)-3.0*DELSDR
      DELSCR=6.*DELSDR/20.
      LMN=C
      GO TC 160
      IF (IPPOINT.NE.0.AND.IPRINT.NE.1) GO TC 320
      WRITE (LOG2,310)
      310  FORMAT (/10X,SHPOINT,5X,22HNORMALIZED MERIOEICNAL,5X,10HTANGENTIAL
      1,5X,11HCNUMBER LINE,7X,EHSECCNO,7X,9HRADIUS CF,/26X,10HCOORDINATE,
      211X,10HCOORDINATE,8X,5HSCLPE,8X,10HDERIVATIVE,5X,9HCURVATURE,/2X)
      IP=IPPOINT
      IF (IPPOINT.GE.49) IP=48
      WRITE (LOG2,315) (L, SU(L), YU(L), YNPRIHE(L), YFFH(E(L)), YFRIME(L), L=1,I
      1P)
      IF (IPPOINT.GE.45) WRITE (LOG2,85)
      IF (IPCINT.GE.45) WRITE (LOG2,315) (L, SU(L), YU(L), YMFRIE(L), YPPMHE(

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1L),YFRIME(L),L=49,INFOINT)
315  FORMAT (12X,I2,14X,F6.4,14X,F7.4,6X,F6.4,6X,F6.4,7X,F8.3)
320  NPOINT=IPCINT
      XNORMC=CHORD1/SS(100)
      AXIALC=SS(100)
      DO 325 I=1,NSTNS
      KFT=KPTS(I)
      CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(1)
      X(100)=XHERE(NSTNS)
      AX=(X(100)-X(1))/99.0
      DO 330 I=2,99
      X(I)=X(I-1)+AX
      CALL CG (XHERE,R(1,J),NSTNS,X,XDUM,YFRIME,100,1)
      CALL CG (XHERE,R(1,J),NSTNS,XHERE,XDUM,TANPI(1,J),NSTNS,1)
      S(1)=0.0
      DO 335 I=2,100
      SS(I)=SS(I-1)+AX*SQRT((1.0+((YFRIME(I)+YFRIME(I-1))/2.0)**2))
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      CALL BQ (J,YS,YP,XS,XP,YSEMI,XSEMI,LOGZ,INFOINT,IPRINT,BETHET(1),BE
1TNET(MN),YZERC,T,YGNE,XCEL,YDEL,Z,XNORMC,LNCT,YPRIME,RAD,SIG
2NA,EFZ,XHERE,X,SS,NSTNS,R,BX,SU,YU,YMFRME,AXIALC,ISTAK)
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      DC 340 I=1,100
      X(I)=X(I)-STACKX
      SS(I)=SS(I)-BX
      DO 345 I=1,NSTNS
      XHERE(I)=XHERE(I)-STACKX
      IF ((IFFLCT.EQ.0.0.R.IFPLOT.EQ.2.0.R.IFPLOT.EQ.4) GO TO 365
      XPLOT=XS(J,1)*SCALE
      YPLOT=Y(S(J,1))*SCALE
      CALL PLCT (XPLOT,YPLOT,3)
      DO 350 I=2,NPOINT
      XPLOT=XS(J,I)*SCALE
      YPLOT=Y(S(J,I))*SCALE
      CALL PLCT (XPLOT,YPLOT,2)
      DO 355 II=1,NPOINT
      I=NPCINT-II+1
      XPLOT=X(P(J,I))*SCALE
      YPLOT=Y(P(J,I))*SCALE
      A1605
      A1810
      A1815
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      A1825
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      A1905
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      A1920
      A1925
      A1930
      A1935
      A1940
      A1945
      A1950
      A1955
      A1960
      A1965
      A1970
      A1975
      A1980
      A1985
      A1990
      A1995
      A2000

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355 CALL FLCT (XPLOT,YPLOT,2)
DO 360 I=2,30
XPLOT=XSEMI(J,I)*SCALE
YPLOT=YSEMI(J,I)*SCALE
CALL FLCT (XPLOT,YPLOT,2)
360 XPLOT=XS(J,1)*SCALE
YPLOT=YS(J,1)*SCALE
CALL FLCT (XPLOT,YPLOT,2)
365 IJDN=0
DO 370 I=1,NSTNS
IF (IFANGS(I).EQ.1) IJDN=1
370 CONTINUE
IF (IJDN.EQ.0) GO TO 380
CALL D1 (SS,X,100,XTEMP,XTEMP,100,1)
DO 375 I=1,NSTNS
CALL D1 (XTEMP,SIGNA,100,XHERE(I),THETA(J,I),1,1)
CALL D1 (XTEMP,YPRIME,100,XHERE(I),ALFHAC(J,I),1,1)
ZCAME(J,I)=R(I,J)*CCS(THETA(J,I))
YCAME(J,I)=R(I,J)*SIN(THETA(J,I))
375 DO 385 I=1,NPOINT
XTEMP(I)=XS(J,I)
385 CALL C1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)
CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
K=1
380 DO 390 I=1,NPCINT
EPS=EPZ(I,K)
ZS(J,I)=RAD(I)*COS(EPS)
YS(J,I)=RAD(I)*SIN(EPS)
XS(J,I)=XTEMP(I)
DO 395 I=1,NPCINT
395 XTEMP(I)=XF(J,I)
CALL D1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)
CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
K=2
400 DO 405 I=1,NPCINT
EPS=EPZ(I,K)
ZP(J,I)=RAD(I)*COS(EPS)
YP(J,I)=RAD(I)*SIN(EPS)
XP(J,I)=XTEMP(I)
405 DO 405 I=1,31

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405      XTEMF(I)=XSEMI(J,I)
        CALL 01 (SS,X,100,XTEMP,XTEMP,31,1)
        CALL 01 (XHERE,R(1,J),NSTNS,XTEMP,RAD,31,0)
        K=3
DO 410 I=1,31
        EPS=EPZ(I,K)
        ZSEMI(J,I)=RAC(I)*CCS(EFS)
        YSEMI(J,I)=RAC(I)*SIN(EFS)
        XSEMI(J,I)=XTMF(I)
        IF (IPRINT.EQ.2) GO TO 465
        IF (LNCT.LE.50) GO TO 415
        WRITE (LOG2,85)
        LNCT=1
415      LNCT=LNCT+5
        WRITE (LCG2,420) J
420      FORMAT (2X,/10X,38H CARTESIAN COORDINATES ON STREAMSURFACE,I3,/,1
10X,8H POINT NO,5X,2H2S,12X,2HXS,12X,2HYS,16X,2HXP,12X,2HYP
2,/,2X)
        I=1
        WRITE (LCG2,430) I,2S(J,I),XS(J,I),YS(J,I),2P(J,I),XF(J,I),YF(J,I)
425      FORMAT (10X,15,3X,1F3E14.5,4X,1P3E14.5)
        I=I+1
        LNCT=LNCT+1
        IF (J.GT.NFCINT) GO TO 440
        IF (LNCT.LE.59) GO TO 425
        WRITE (LOG2,435)
435      FORMAT (1H1,9X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2
1HXP,12X,2HYP,/,2X)
        LNCT=2
        GO TO 425
        IF (LNCT.LE.50) GO TO 445
        WRITE (LCG2,85)
        LNCT=1
445      LNCT=LNCT+3
        WRITE (LCG2,450)
450      FFORMAT (2X,/10X,8HPOINT NO,4X,5HZSEMI,9X,5HXSENI,9X,5HYSEMI,/,2X)
        I=1
        WRITE (LCG2,460) I,ZSEMI(J,I),XSEMI(J,I),YSEMI(J,I)
455      FORMAT (10X,15,3X,1F3E14.5)
        I=I+1

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LNCT=LNCT+1
IF (I.GT.31) GO TO 465
IF (LNCT.LE.59) GO TO 455
WRITE (LOG2, 85)
WRITE (LOG2, 450)
LNCT=4
GO TO 455
CONTINUE
465 IF (IPRINT.EQ.1) GO TO 530
VOL=0.0
DO 470 J=2,NLINES
VOL=YCL+((XS(J,1)-XP(J,1))*2+(YS(J,1)-YF(J,1))*2)+(XS(J-1,1)-X
1P(J-1,1))*2+(YS(J-1,1)-YF(J-1,1))*2)*(ZS(J,1)+2P(J,1)+2P(J-1,1)
2-ZP(J-1,1))*PI/32.0
470 DO 470 I=2,NPCINT
VOL=VOL+((SQR((XS(J,I)-XP(J,I))*2+(YS(J,I)-YF(J,I))*2)+SQR((XS
1(J,I-1)-XP(J,I-1))*2+(YS(J,I-1)-YF(J,I-1))*2))*(SQR((XS(J,I-1)-
2XS(J,I))*2+(YS(J,I-1)-YS(J,I))*2)+SQR((XP(J,I-1)-XP(J,I))*2+(Y
3P(J,I-1)-YF(J,I))*2)+(SQR((XS(J-1,I)-XF(J-1,I))*2+(YS(J-1,I)-Y
4P(J-1,I))*2)+SQR((XS(J-1,I-1)-XF(J-1,I-1))*2+(YS(J-1,I-1)-YF(J-
5,I,I-1))*2)*(SQR((XS(J-1,I-1)-XS(J-1,I))*2+(YS(J-1,I-1)-YF(J-1,I-
6,I))*2)+SQR((XP(J-1,I-1)-XF(J-1,I))*2+(YP(J-1,I-1))*2+
(ZS(J,1)+2S(J,I-1)+2P(J,I)+2P(J,I-1)-ZS(J-1,I)-ZS(J-1,I-1)-2P(
8J-1,I)-2P(J-1,I-1))/32.0
IF (LNCT.LE.56) GO TO 475
LNCT=1
WRITE (LCG2, 85)
475 LNCT=LNCT+4
WRITE (LCG2, 480) VOL
480 FORMAT (2X,/4CX,25H VOLUME OF BLADE SECTION =,1FFE11.4,/40X,3
1S(1H*))
IF (IJDCUM.EQ.0) GO TO 530
WRITE (LOG2, 85)
WRITE (LOG2, 485)
485 FORMAT (43X,43HBLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS,/43X,4
1S(1H*))
IDUM=7
LNCT=3
DO 525 I=1,NSTNS
IF (IFANGS(I).EQ.0) GO TO 525

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DO 495 J=1,NLINES
CALL D1 (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,1,0)
CALL CG (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,ZR(J),1,1)
DO 490 K=1,NPOINT
SS(K)=XS(J,K)
RAD(K)=YS(J,K)
XTMF(K)=XP(J,K)
X(K)=YP(J,K)
XDUM=XDUM-STACKX
CALL D1 (SS,RAD,NPOINT,XDUM,YY1,1,1)
CALL D1 (XTMF,X,NPCINT,XCUM,YY2,1,1)
H1=YY1/R(I,J)
H2=Y2/R(I,J)
TC(J)=ABS(ATAN(H1/SQRT(1.-H2**2))-ATAN(H2/SQRT(1.-H2**2)))/(.2.*PI)
A267 F
1*FLOAT(NBLADE)
CONTINUE
CALL CG (ZCAMB(1,I),YCAMB(1,I),NLINES,ZCAMB(1,I),XDUM,RLE,NLINES,1
1)
IF (LNCT+IDUM+NLINES.LE.59) GO TO 500
WRITE (LOG2,85)
L,C1=2
LNCT=LNCT+IDUM+NLINES
WRITE (LOG2,505) I,NLINES
FORMAT (//,4X,BSTATION ,I2,5X,17HNUMBER OF RADII= ,I2,/,56X,6H
1RADUS,5X,7HSECTION,6X,4HLEAN,9X,5HBLADE,7X,5HANGLE,
26X,5HANGLE,7X,8HBLOCKAGE,/ ,2X)
DO 510 J=1,NLINES
EPS=(THETA(J,I)-ATAN(RLE(J)))*C1
ALPH5=ALPHA(J,I)
ALP=(ATAN((TANP-I(I,J)*TAN(EPS/C1)+ALFH8*SQRT(1.+TANFH(I,J)**2))/
1(C1.-TANPH(I,J)*ZR(J)))*C1
WRITE (LOG2,515) R(I,J),ALP,EFS,TC(J),THETA(J,I)
IF (IFUNCH.EQ.0) GO TO 510
WRITE (LOG3,520) R(I,J),ALP,EPS,TC(J),THETA(J,I),I,J
CONTINUE
510 FORMAT (30X,5F12.4)
520 FCRMAT (5F12.7,2I3)
525 CONTINUE
530 IF (IFPLCT.LT.2.0R.IFPLCT.EG.4) GC TO 535
CALL FQ (ISTAK,PLTSZE,2,TITLE,IKDUM,IFPLOT)

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3I-1)-YP(J,I))**2))/4.0
AREA=AREA+DELA
XINY=XINT+DELA*(XS(J,I)**4*XS(J,I-1)+XP(J,I)**4*XP(J,I-1))/4.0
YINT=YINT+DELA*(YS(J,I)+YP(J,I)+YF(J,I)+YF(J,I-1))/4.0
YINT=YINT/AREA
A3025
XINT=XINT/AREA
A3030
X1=(XS(J,1)+XP(J,1))/2.
A3035
Y1=(YS(J,1)+YP(J,1))/2.
A3040
T1=SQR((XS(J,1)-XP(J,1))**2+(YS(J,1)-YF(J,1))**2)
A3045
F=0.
A3050
U=0.
A3055
DO 570 I=2,NPCINT
T2=SQR((XS(J,I)-XP(J,I))**2+(YS(J,I)-YF(J,I))**2)
A3060
X2=(XS(J,I)+XP(J,I))/2.
A3065
Y2=(YS(J,I)+YP(J,I))/2.
A3070
DELU=SQR((X2-X1)**2+(Y2-Y1)**2)
A3075
U=U+DELU
A3080
TAV3=(T1**3+T2**3)/2.
A3085
F=F+TAV3*DELU
A3090
X1=X2
A3100
Y1=Y2
A3105
T1=T2
A3110
TORCCN=((1.0/3.0)*F)/(1.0+(4.0/3.0)*F, AREA/U**2)
A3115
A3120
A3125
A3130
A3135
A3140
A3145
A3150
A3155
A3160
A3165
A3170
A3175
A3180
A3185
A3190
A3195
A3200

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DO 575 I=2,NPCINT
X0=(SQR((XS(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YF(J,I-1))**2)+SQR((  

1XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2))/2.0
Y0=(SQR((XS(J,I)-XS(J,I-1))**2+(YS(J,I)-YS(J,I-1))**2)+SQR((XP(  

J,I)-XP(J,I-1))**2+(YP(J,I)-YP(J,I-1))**2))/2.0
IXD=YD*YD*YC*XD/12.0
IYO=XD*XD*YO*YD/12.0
ANG=ATAN((YS(J,I)+YF(J,I))-YS(J,I-1))/(XP(J,I)-XP(  

1(J,I-1)-XS(J,I-1)))
COSANG=COS(2.0*ANG)
IXN=(IXD+IYD+((IXD-IYD)*COSANG)/2.0
IYN=(IXD+IYC-((IXD-IYC)*COSANG)/2.0
IXYN=0.0
IF (ANG.NE.0.0) IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*SIN(2.0*ANG))

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A3205
A3210
A3215
A3220
A3225
A3230
A3235
A3240
A3245
A3250
A3255
A3260
A3265
A3270
A3275
A3280
A3285
A3290
A3295
A3300
A3305
A3310
A3315
A3320
A3325
A3330
A3335
A3340
A3345
A3350
A3355
A3360
A3365
A3370
A3375
A3380
A3385
A3390
A3395
A3400

DELA=XY*YD
YMN=(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0-YINT
XMN=(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0-XINT
IX=IX+IXN+DELA*YMN*YHN
IY=IY+IYN+DELA*XMN*XHN
ANG=ATAN(2.0*IY/(IX-IX))
IPX=(IX+IY)/2.0+(IX-IX)/2.0*COS(ANG)-IXY*SIN(ANG)
IPY=(IX+IY)/2.0-(IX-IX)/2.0*COS(ANG)+IXY*SIN(ANG)
ANG=ANG/2.0*C1
IF (1PRINT.EQ.1) GO TO 640
IF (LNCT.LE.45) GO TO 580
WRITE (LOG2,85)
LNCT=1
LNCT=LNCT+16
WRITE (LCG2,585) J,ZOUT(J),AREA,XINT,YINT,IX,IY,IPX,ANG,IPY,AN
16
585  FORMAT (2X,'/50X,14SECTION NUMBER,13,3X,5H"Z"=,F9.4,/50X,34H***'
1******/20X,1ESECTION PROPERTIES,7X,1
22HSECTION AREA,26X,1H=,1PE12.4:/,45X,20HLOCATION OF CENTRCIE,11X,
34HXBAR,3X,1H=,2E12.4,/45X,22HRELATIVE 10 STACK AXIS,9X,4HYBAR,3X,1
4H=,E12.4,/45X,22HSEC AND MOMENTS OF AREA,9X,ZHIX,5X,1H=,E12.4,/4
55X,14HABUT CENTRCIE,17X,2HIXY,5X,1H=,E12.4,/76X,3HIXY,4X,1H=E12.
64,/45X,24HPRINCIPAL SECCNC MOMENTS,7X,3HIFX,4X,1H=E12.4/4H(AT,
70PF7,2,21H DEGREES 10 0X* AXIS),/45X,22HCF AREA ABOUT CENTRICD,9X
8,3HIFY,4X,1H=,1FE12.4,4H (AT,0PF7,2,21H DEGREES TO 0Y* AXIS)
WRITE (LOG2,590) TORCON
FORMAT (/45X,18HTORSIONAL CONSTANT,20X,1H=,1PE12.4,/2X)
LNCT=LNCT+3
IF (LNCT.LE.50) GO TO 595
WRITE (LOG2,85)
LNCT=1
LNCT=LNCT+5
WRITE (LCG2,600)
FORMAT (2X,'/20X,19SECTION COORDINATES,/2X)
WRITE (LOG2,605)
FORMAT (31X,8HPCINT NO,5X,2HXS,12X,2HYS,16X,2HXF,12X,2HVF,/2X)
DO 610 I=1,NPOINT
LNCT=LNCT+1
IF (LNCT.LE.60) GO TO 610

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```

LNCT=4
      WRITE (LOG2,605)
      WRITE (LOG2,605)
      WRITE (LOG2,615) I,XS(J,I),YS(J,I),XP(J,I),YP(J,I)
610     FORMAT (31X,I5,3X,1F2E14.5,4X,2E14.5)
615     IF (LNCT.LE.5) GO TO 620
      LNCT=1
      WRITE (LOG2,605)
      LNCT=LNCT+3
      WRITE (LOG2,625)
      FORMAT (2X,/,31X,8HPOINT N0,5X,5HXSEMI,9X,5HYSEMI,/,2X)
      DO 630 I=1,31
      LNCT=LNCT+1
      IF (LNCT.LE.60) GO TO 630
      WRITE (LOG2,605)
      WRITE (LOG2,625)
      LNCT=4
      WRITE (LOG2,635) I,XSEMI(J,I),YSEMI(J,I),
      FORMAT (31X,I5,3X,1F2E14.5)
      IF (IFPLCT.LT.2) GO TO 690
      IF (IFPLCT.EQ.4) GO TO 660
      XPLCT=XS(J,1)*SCALE
      YPLCT=YS(J,1)*SCALE
      CALL PLCT (XPLOT,YPLOT,3)
      DO 645 I=2,NPOINT
      XPLOT=XS(J,I)*SCALE
      YPLOT=YS(J,I)*SCALE
      CALL PLCT (XPLOT,YPLOT,2)
      DO 650 II=1,NPOINT
      I=NPCINT(I-1)
      XPLOT=XP(J,I)*SCALE
      YPLOT=YP(J,I)*SCALE
      CALL PLCT (XPLOT,YPLOT,2)
650     DO 655 I=2,30
      XPLCT=XSEMI(J,I)*SCALE
      YPLCT=YSEMI(J,I)*SCALE
      CALL PLCT (XPLOT,YPLOT,2)
655     XPLCT=XS(J,1)*SCALE
      YPLOT=YS(J,1)*SCALE
      CALL PLCT (XPLOT,YPLOT,2)

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A3605
A3610
A3615
A3620
A3625
A3630
A3635
A3640
A3645
A3650
A3655
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A3670
A3675
A3680
A3685
A3690
A3695
A3700
A3705
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A3745
A3750
A3755
A3760
A3765
A3770
A3775
A3780
A3785
A3790
A3795
A3800

660   GO TC 690
       CALL SYMBOL (19.9,2.0,.175,22H CARTESIAN SECTION NU. ,0.0,22)
       XJ=J
       CALL NUMBER (23.75,2.0,.175,XJ,0.0,-1)
       CALL SYMBOL (20.6,1.0,.175,10H STAGGER = ,0.0,10)
       STAGER=ATAN((YS(J,NPOINT)+YF(J,NPOINT)-YS(J,1))-YP(J,1))/XS(J,NPOINT)
       1NT3+XP(J,NFCINT)-XS(J,1)-XP(J,1))*C1
       CALL NUMBER (22.35,1.0,.175,STAGER,0.0,3)
       CALL PLCT (22.0,5.25,-3)
       SINSIG=SIN(STAGER/C1)
       COSSIG=COS(STAGER/C1)
       YPLOT=4.75
       XPLOT=4.75*SINSIG/CCSSIG
       IF (ABS(XPLOT).LE.22.0) GO TO 665
       XPLOT=22.0
       YPLOT=-22.0/SINSTG*COSSTG
       CALL PLCT (XPLOT,YPLOT,3)
       XPLCT=-XPLCT
       YPLOT=-YPLOT
       CALL PLCT (XPLOT,YPLOT,2)
       XPLOT=22.0
       YPLOT=-22.0*SINSTG/COSSTG
       IF (ABS(YPLOT).LE.4.75) GO TO 670
       YPLOT=-4.75
       XPLOT=4.75/SINSTG*CCSSIG
       CALL PLCT (XPLOT,YPLOT,3)
       XPLCT=-XPLCT
       YPLOT=-YPLOT
       CALL PLCT (XPLOT,YPLOT,2)
       XPLCT=SCALE*(XS(J,1)*CCSSIG+YS(J,1)*SINSTG)
       YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)
       CALL PLCT (XPLOT,YPLOT,3)
       DO 675 I=2,NPOINT
       XPLCT=SCALE*(XS(J,I)*COSSTG+YS(J,I)*SINSTG)
       YPLOT=SCALE*(YS(J,I)*COSSTG-XS(J,I)*SINSTG)
       CALL PLCT (XPLOT,YPLOT,2)
       DO 680 II=1,NPOINT
       I=NPCINT+1-II
       XPLCT=SCALE*(XP(J,I)*CCSSIG+YP(J,I)*SINSTG)
       YPLOT=SCALE*(YP(J,I)*COSSTG-XP(J,I)*SINSTG)

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```

6 E0      CALL PLCT (XPLOT,YPLOT,2)
          DO 605 I=2,30
          XPLOT=SCALE*(XSEMI(J,I)*COSSTG+YSEMI(J,I)*SINSTG)
          YPLOT=SCALE*(YSEMI(J,I)*COSSTG-XSEMI(J,I)*SINSTG)
          CALL PLCT (XPLOT,YPLOT,2)
          XPLOT=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)
          YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)
          CALL PLCT (XPLOT,YPLOT,2)
          CALL PLOT (23.0,-5.25,-3)
          CONTINUE
6 65      IF (IFPLOT.NE.0) CALL PLOTE
          GO TO 710
          WRITE (LOG2,705) J
          705  FORMAT (10X,8HFILE#, I2)
          CONTINUE
          STOP
          END
          A3805-
          A3810
          A3815
          A3820
          A3825
          A3830
          A3835
          A3840
          A3845
          A3850
          A3855
          A3860
          A3865
          A3870
          A3875
          A3880
          A3885-

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```

SUBROUTINE BQ (IBL,YS,YP,XS,XP,YSEMI,XSEMI,LOG2,N,IFRINT,BETA1,BET
1A2,YZERC,T,YONE,XDEL,YDEL,Z,XNORMC,LNCT,DX,Y,CY,SIGMA,SS1,XHERE,X
2SS,NSTNS,R,BX,XM,YN,AN,AXIALC,ISTAK)
REAL IX,IY,IXY,IPX,IPY,IXC,IYD,IXN,IYN,IXY\N
DIMENSION YS(15,81),YF(15,81),XS(15,81),XP(15,61),YSEMI(15,31)
1, XSEMI(15,31), S(81), Y(100), THICK2(81), XM(82), YP(81), AP(81),
2 XHERE(100), X(100), SS(100), R(10,15), DX(100), CY(100), SS1(100),
3 SIGMA(100)
5 FORMAT (1H1)
PI=3.1415926535
C1=180.0/PI
IF (IFRINT.EQ.2) GO TO 15
WRITE (LCG2,10) IBL,BETA1,BETA2,YZERO,T,YCNE,Z,AXIALC
FORMAT (1H1,44X,43HSTREAMSURFACE GEOMETRY ON STREAMLINE NUMBER,I3,
1/45X,46(1H*),/,20X,5HHEET A1,11X,1H=F7.3,EX,20H(GLADE INLET
2/,20X,5HHEET A2,11X,1H=F7.3,6X,21H(GLADE OUTLET ANGLE.),/,20X,5H
3ZERO,11X,1H=F8.5,5X,51H(GLADE LEADING EDGE RADIUS AS A FRACTION O
4F CHORD.),/,20X,1H,F8.5,5X,4SH(GLADE MAXIMUM THICKNESS AS
5 A FRACTION OF CHORD.),/,20X,4HYONE,12X,1H=F8.5,5X,60H(GLADE TRAI
6LING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.),/,20X,1H,F
7=F7.4,6X,59H(LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN
8LINE.),/,20X,4HCORD,12X,1H=F7.4,6X,36H(MERIDIONAL CHORD OF SECTIO
9N.)
15 CHORD=XNORMC/(1.0-YZERO+XNORMC*(YZERO+ABS(YCNE*SIN(BETA2/C1))))
FCSLMN=1.0-CHORD*(YZERO+AES(YONE*SIN(EE TA2/C1)))
AX=1./99.
DX(1)=0.
DO 25 IK=2,100
DX(IK)=DX(IK-1)+AX
CALL D1 (XM,YN,N,DX,DY,100,1)
SIGMA(1)=0.
DO 25 K=2,100
SIGMA(K)=SIGMA(K-1)+SQRT((DX(K)-DX(K-1))**2+(DY(K)-DY(K-1))**2)
CALL D1 (DX,SIGMA,100,XP,S,N,1)
YZERO=YZERO*CHORD/FCSLMN
YONE=YONE*CHORD/FCSLMN
T=T*CHORD/FCSLMN
S(1)=0.
AT=(YZERC-T/2.0)/(2.*0.**Z**2)
CT=(1/2.*0.-YZERO)*3.0/(2.*0.*Z)
20
25

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```

CT=YZERO
ET=(YONE-T/2.0)/(1.0-Z)*3-1.5*(YZERO-T/2.0)/(Z**2*(1.0-Z))
FT=1.5*(YZERO-T/2.0)/Z**2
HT=T/2.0
DO 40 J=1,N
SN=S(J)/S(N)
IF (SN.GT.2) GO TO 30
THICK2(J)=(AT*SN**2+CT)*SA+CT
GC TC 35
SN=SN-Z
30 THICK2(J)=(ET*SN+FT)**SN**2+FT
FYPR=1./SQRT(1.+AM(J)**2)
YPRIME=AM(J)
XS(TIBL,J)=(XM(J)-THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
YS(TIBL,J)=(YM(J)+THICK2(J)*FYPR)*FCSLMN
XP(TIBL,J)=(XM(J)+THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
YP(TIBL,J)=(YM(J)-THICK2(J)*FYPR)*FCSLMN
AM(J)=ATAN(AM(J))*C1
XM(J)=(XM(J)+YZERO)*FCSLMN
YM(J)=YM(J)*FCSLMN
THICK2(J)=THICK2(J)*FCSLMN
40 S(J)=S(J)*FCSLMN
YZERC=YZERO*FCSLMN
AREA=PI/2.0*YZERO**2
XINT=YZERO*(1.0-COS(BETA1/C1)*4.0/(3.0*PI))*AREA
YINT=-4.0/(3.0*PI)*YZERO*AREA*SIN(BETA1/C1)
DO 45 J=2,N
DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
AREA=AREA+DELA
XINT=XINT+DELA*(XM(J)+XM(J-1))/2.0
YINT=YINT+DELA*(YM(J)+YM(J-1))/2.0
XBAR=XINT/AREA
YBAR=YINT/AREA
XBARB=XBAR
YBAR=YBAR+YDEL/AXIALC
XBAR=XBAR+XDEL/AXIALC
CALL D1(XM,AM,DX,SS1(1,1),100,1)
DO 50 IK=1,100
SS1(IK,1)=TAN(SS1(IK,1)/C1)

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Y(IK)=DX(IK)*FCSLMN
SIGMA(IK)=DX(IK)*FCSLMN+YZERO
CALL D1 (SIGMA,Y,100,DX,0Y,100,1)
CALL D1 (SIGMA,SS1(1,1),100,DX,Y,100,1)
CALL D1 (DX,DY,100,XBAR,XAB,1,1)
CALL E1 (DX,Y,100,XBAR,XBC,1,1)
XBAR=XBARB
YBAR=YBARB
IX=0.0
IY=0.0
IXY=0.0
DO 55 J=2,N
DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
IXD=(THICK2(J)+THICK2(J-1)**3*(S(J)-S(J-1))/12.0
IYD=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))*3/12.0
CCSANG=CCS((AM(J)+AM(J-1))/C1)
IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
IXYN=0.0
IF ((AN(J)+AM(J-1)).NE.0.) IXN=((IXA-IYN)*CCSANG-IXC*IYD)/(2.0*S
1 IN ((AN(J)+AM(J-1))/C1)
IX=IX+IXN+CELA*((YH(J)+YH(J-1))/2.0-YEAR)**2
IY=IY+IYN+CELA*((XH(J)+XH(J-1))/2.0-XYEAR)**2
IXY=IXY+IXYN+DELA*(YBAR-(YH(J)+YH(J-1))/2.0)*(XBAR-(XH(J)+XH(J-1))
1/2.0)
ANG=ATAN(2.0*IXY/(IY-IX))
IPX=(IX+IY)/2.0+(IX-IX)/2.0*COS(ANG)-IXY*SIN(ANG)
IPY=(IX+IY)/2.0-(IX-IX)/2.0*COS(ANG)+IXY*SIN(ANG)
ANG=ANG/2.0+C1
STAGER=ATAN(YM(N)/XM(N))*C1
XML=XN(N)
YML=YH(N)
CAMBER=BETA1-BETA2
IF (IPRINT.EQ.2) GO TO 95
LNCT=47
WRITE (LCG2,60) CHORD, STAGER, CAMBER, AREA, XBAR, YEAR, IX, IY, ANG, I
1PX, ANG, IPY, ANG
60 FORMAT (/16X,100HNCRALISED RESULTS - ALL THE FOLLOWING REFER TO
1ABLACE HAVING A MERIDIONAL CHORC PROJECTION OF UNITY, /,16X,100(1H*
2),//20X,11HELADE CHORD, 4X,1=,F7.4,/,20X,16HSTAGGER ANGLE =,F7.3

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3,/,20X,16HCAMBER ANGLE =,F7.3,/,2CX,16HSECTION AREA =,F7.5,/          B 605
4/,20X,45HLLGATION OF CENTROID RELATIVE TO LEADING EDGE,/,30X,6HXB      B 610
5AR =,F8.5,/,30X,6HYEAR =,F8.5,/,20X,27HSECOND MOMENTS CF AREA ABO      B 615
6UT CENTROID,/,30X,6HIX =,F8.5,/,30X,6HY =,F8.5,/,30X,6HIXY      B 620
7=,F8.5,/,20X,58HANGLE OF INCLINATION OF (CNE) PRINCIPAL AXIS TO *      B 625
8X,AXIS =,F7.3,/,20X,47HPRINCIPAL SECOND MOMENTS OF AREA ABOUT CE      B 630
9NTROID,/,30X,6HIPX =,F7.5,6X,3H(AT,F7.3,15H WITH 'X' AXIS),/,30X      B 635
$,6HIFY =,F7.5,6X,3H(AT,F7.3,15H WITH 'Y' AXIS),/,)      B 640
FORMAT (27X,5HPCINT,8X,24HM E A N L I N E C A T A,13X,23HSURFACE      B 645
100RCINATE DATA,/,27X,6HNUMBER,5X,1HX,7X,1HY,5X,15HANGLE THICKNESS      B 650
2,9X,2HXS,6X,2HY$,6X,2HXP,6X,2HYP,/,)      B 655
WRITE (LOG2,65)      B 660
GO ?5 J=1,N      B 665
IF (LNCT.NE.60) GO TO 70      B 670
WRITE (LOG2,5)      B 675
WRITE (LOG2,65)      B 680
LNCT=4      B 685
LNCT=LNCT+1      B 690
TM=THICK2(J)*2.0      B 695
75 WRITE (LOG2,80) J,XM(J),YM(J),AN(J),TR,XS(IBL,J),YS(IBL,J),XF(IBL,      B 700
1,J),YF(IBL,J)      B 705
FORMAT (27X,I3,F13.5,F8.5,F7.3,F8.5,F16.5,3F8.5)      B 710
DO 85 J=1,N      B 715
XM(J)=XS(IBL,J)      B 720
YM(J)=YS(IBL,J)      B 725
AN(J)=XF(IBL,J)      B 730
A4=AXIALC**2      B 735
THICK2(J)=YP(IBL,J)      B 740
WRITE (LOG2,90) IBL      B 745
FORMAT (1H1,45X,33HNORMALISED PLOT OF SECTION NUMBER,I3,/2X)
CALL EQ (N,LOG2,XM,YH,AN,THICK2)      B 750
95 A2=AXIALC**2      B 755
A4=A2**2      B 760
IX=IX*A4      B 765
IY=IY*A4      B 770
IXY=IXY*A4      B 775
IPX=IPX*A4      B 780
IPY=IPY*A4      B 785
IF (ISTAK.GT.1) GO TO 100      B 790
XBAR=ISTAK      B 795
IF (ISTAK.EQ.0) YBAR=0.      B 800

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IF (CSIAK.EQ.1) YBAR=YML
RLE=YZERO*AXIALC
CHORD=CHORD*AXIALC
AREA=AREA*A2
XC=RLE-XBAR*AXIALC-XDEL
YC=-YBAR*AXIALC-YDEL
IF (IPRINT.EQ.2) GO TO 120
WRITE (LCG2,105) CHCRD,RLE,XC,YC,AREA,IY,IY,IFX,ANG,IPY,ANG
FCRMAT (1H1,31X,69HC)IHESSIONAL RESULTS - ALL RESULTS REFER TC A BL
1AEC CF SPECIFIED CHCRD,/, 32X,69H***** **** **** **** **** **** ****
2**** **** **** **** **** **** **** **** **** **** **** **** **** ****
3PE12.5,/,20X,10HL.E.RADIUS,5X,1H=,1PE12.5,8X,14HCENTERE0 AT X=,1P
4E13.5,3H Y=,1FE13.5,/,20X,16HSECTION AREA =,1PE12.5,/,20X,37HS
5ECONC MENTS OF AREA ABOUT CENTROID,/,30X,6HIX =,1PE12.5,/,30X
6,6HIX =,1FE12.5,/,30X,6HIX XY =,1PE12.5,/,20X,47HPRINCIPAL SECON
7D MOMENTS OF AREA AEOUT CENTROID,/,30X,6HIPX =,1PE12.5,5H (AT,0
8PF7.3,15H WITH 'X' AXIS),/30X,6HIPY = -1FE12.5,5H (AT,0PF7.3,15H
9 WITH 'Y' AXIS),/)

WRITE (LCG2,110)
WRITE (LCG2,115)
FORMAT (124H PT SUCTION----SURFACE
1RFACE FT SUCTION----SURFACE
2FACE)
FORMAT (4X,2HNO,8X,1HX,13X,1HY,13X,1HX,13X,
11HY,13X,1HX,13X,1HY,/)
LNCT=24
LNCT=24
DO 135 J=1,N
XS(IEL,J)=(XS(IEBL,J)-XBAR)*AXIALC-XDEL
YS(IEBL,J)=(YS(IEBL,J)-YBAR)*AXIALC-YDEL
XP(IEL,J)=(XP(IEBL,J)-XBAR)*AXIALC-XDEL
YP(IEBL,J)=(YP(IEBL,J)-YBAR)*AXIALC-YDEL
IF (IPRINT.EQ.2) GO TO 135
IF ((J/2)*2.NE.J) GOTO 135
IF (LNCT.NE.60) GO TO 125
LNCT=4
WRITE (LCG2,5)
WRITE (LCG2,110)
WRITE (LCG2,115)
LNCT=LNCT+1
JH1=J-1
110
115
120
125

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      WRITE (LOG2,130) JM1,XS(IBL,JM1),YS(IEL,JR1),XP(IEBL,JM1),YF(IEBL,JM
11),J,XSC(IBL,J),YS(IBL,J),XP(IBL,J),YP(IBL,J)
      FORMAT (3X,I3,4(2X,1PE12.5),6X,I3,4(2X,1PE12.5))
      CNTINLE
130      IF (IPRINT.EQ.2) GO TO 150
      IF (LNCT.GT.24) WRITE (LOG2,140)
      FFORMAT (1H1)
      IF (LNCT.GT.24) LNCT=2
      LNCT=LNCT+5
      WRITE (LOG2,145)
      FFORMAT (2X,/48X,37HPOINTS DESCRIBING LEAVING EDGE RADIUS,//,48X,9
1      1HPOINT NO.,6X,1HX,13X,1HY,/2X),
      EPS=EET A1+180.0
      DO 160 J=1,31
      XSEMI(IBL,J)=XC-RLE*SIN(EFS/C1)
      YSEMI(IBL,J)=YC+RLE*COS(EFS/C1)
      EPS=EPS-6.0
      IF (IPRINT.EQ.2) GO TO 160
      WRITE (LOG2,155) J,YSEMI(IBL,J),YSEMI(IBL,J)
      LNCT=LNCT+1
      FFORMAT (48X,I5,1PE17.5,1PE14.5)
150      CONTINUE
160      SSURF=AXIALC
      SS2=EX-AXIALC*XBAR-XDEL
      SBAR=SS2+AXIALC*XBARFB+XDEL
      DO 165 IK=1,100
      165      SS(IK)=SS(IK)-SBAR
      CALL D1 (SS,X,100,0,SEAR,1,1)
      CALL D1 (X+ERE,R(1,IBL),NSTNS,SBAR,RXEAR,1,0)
      XBARC=XBAR
      YBARC=YBAR
      XBAR=XBARB+XDEL/AXIALC
      YBAR=YBARB+YDEL/AXIALC
      SS1(1,1)=SS(1)
      S23=AXIALC/99.
      SS(1)=SS(1)+SS2
      DO 170 IK=2,100
      170      SS1(IK,1)=SS(IK)
      SS(IK)=SS(IK-1)+S23
      SIGMAC=(XAB-YBAR)/RXBAR*AXIALC
      81005
      81010
      81015
      81020
      81025
      81030
      81035
      81040
      81045
      81050
      81055
      81060
      81065
      81070
      81075
      81080
      81085
      81090
      81095
      81100
      81105
      81110
      81115
      81120
      81125
      81130
      81135
      81140
      81145
      81150
      81155
      81160
      81165
      81170
      81175
      81180
      81185
      81190
      81195
      81200

```

```

00 175 IK=2,100          B1205
IF (XBAR.EQ.DX(IK)) GO TO 185      B1210
IF (XBAR.GT.DX(IK-1).AND.XBAR.LT.DX(IK)) GC TC 190      B1215
CONTINUE                         B1220
WRITE (LOG2,180)                  B1225
FORMAT (1H1,23H XBAR CANNOT BE LOCATED)      B1230
SIGMA(IK)=SIGRAC                  B1235
KL=IK+1                           B1240
GO TC 195                         B1245
KL=IK                             B1250
SIGMA(IK-1)=SIGMAO                B1255
SSDUM=SS(KL-1)                   B1260
SS(KL-1)=0.                         B1265
YP1=XBC                            B1270
RX1=RXBAR                          B1275
DO 200 IK=KL,100                  B1280
XSURF=SS2+DX(IK)*SSLRF+SS1(1,1)      B1285
CALL D1 (SS1(1,1),X,100,XSURF,XCUM,1,1)      B1290
CALL D1 (SS1(1,1),X,130,XSURF,XDUM,1,1)      B1295
CALL C1 (SS1(1,1),X,100,XSURF,XDUM,1,1)      B1300
CALL D1 (XHERE,R(1,IBL),NSTAS,XCUM,RX2,1,0)      B1305
SIGMA(IK)=SIGMA(IK-1)+(Y(IK)/RX2+YP1/RX1)/2.* (SS(IK)-SS(IK-1))
YP1=Y(IK)                          B1310
RX1=RX2                            B1315
SS(KL-1)=SSDUM                     B1320
SSDUM=SS(KL)                       B1325
SIGDUM=SIGMA(KL)                   B1330
SIGRA(KL)=SIGRAC                   B1335
SS(KL)=0.                           B1340
RX1=RXBAR                          B1345
YP1=XBC                            B1350
KJ=KL-1                           B1355
DO 205 IK=1,KJ                     B1360
KJ=KL-IK                          B1365
XSURF=SS2+DX(KJ)*SSLRF+SS1(1,1)      B1370
CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)      B1375
CALL D1 (XHERE,R(1,IBL),NSTAS,XDUM,RX2,1,0)      B1380
SIGMA(KJ)=SIGMA(KJ+1)-(Y(KJ)/R)(2+YP1/RX1)/2.* (SS(KJ+1)-SS(KJ))      B1385
YP1=Y(KJ)                          B1390
RX1=RX2                            B1395

```

```

SIGMA(IK)=SIGDUM
SS(IK)=SSDUM
00 210 IK=1,100
SS(IK)=SS1(IK,1)
210 XBAR=XBARC
YBAR=YBARC
DO 215 IK=1,N
SS1(IK,1)=SS2+((XS(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
215 SS1(IK,2)=SS2+((XP(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
00 220 IK=1,31
SS1(IK,3)=SS2+((XSEMI(IEL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
CALL D1 (SS,X,100,SS1(1,1),N,1)
CALL D1 (SS,X,100,SS1(1,2),N,1)
CALL D1 (SS,X,100,SS1(1,3),N,1)
IF (ISTAK.GT.1) GO TO 230
IF (ISTAK.EQ.1) SIGMAO=SIGMA(100)
IF (ISTAK.EQ.0) SIGMAO=SIGMA(1)
DC 225 IK=1,100
SIGMAC(IK)=SIGMA(IK)-SIGMAC
225 00 235 IK=1,100
DX(IK)=(DX(IK)-XBAR)*AXIALC-XDEL
CY(IK)=(CY(IK)-YBAR)*AXIALC-YDEL
DO 245 IK=1,3
IF (IK.EQ.3) NNN=31
IF (IK.EQ.1.OR.IK.EQ.2) NNN=N
00 240 IK=1,NNN
IF (IK.EQ.1) YP1=YS(IBL,IK)
IF (IK.EQ.2) YP1=YP(IBL,IK)
IF (IK.EQ.3) YP1=YSEMI(IBL,IK)
IF (IK.EQ.1) RX1=XS(IBL,IK)
IF (IK.EQ.2) RX1=XP(IBL,IK)
IF (IK.EQ.3) RX1=XSEMI(IBL,IK)
CALL D1 (DX,DY,100,RX1,FYEAR,1,1)
DELLY=YP1-RXBAR
CALL D1 (XHERE,R(1,IBL),NSTNS,SS1(IK,IK),RAB,1,0)
DELSIG=CELLY/RAB
CALL D1 (DX,SIGMA,100,RX1,XAB,1,1)
240 SS1(IK,IK)=XA0+DELSIG
245 CONTINUE
RETURN
END

```

```

SUBROUTINE CO (XDATA, YDATA, NDATA, XIN, YOUT, YFRIE, NX, NY, NNOT)
      REAL H
      DIMENSION A(65), B(65), D(65), XDATA(1), YDATA(1), XIN(1),
     1 YOUT(1), YFRIE(1)
      IF (NDATA-2) 120, 5, 25
      IF (NNOT-1) 10, 20, 10
      5   DO 15 I=1,NXY
      10   YOUT(I)=((YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1)))*(XIN(I)-XDATA(1)
     1 )+YDATA(1)
      15   IF (NNOT) 120, 120, 25
      20   OC 30 I=1, NXY
      25   YFRIE(I)=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))
      30   GO TC 120
      35   CONTINUE
      40   E1=1.0
      45   E2=1.0
      50   A(1)=1.0
      55   B(1)=-E1
      60   D(1)=0.0
      65   N=NDAYA-1
      70   DC 40 I=2,N
      75   A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*E(I-1)/6.0
      80   1+E(I-1)
      85   B(I)=(XDATA(I+1)-XDATA(I))/E.0
      90   D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-((YCATA(I)-YCATA(I-
     1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*G(I-1)/6.0/A(I-1))
      95   A(NDATA)=E2
      100  B(NDATA)=1.0
      105  D(NDATA)=0.0
      110  M(NDATA)=A(NDATA)*D(N)+(A(NDATA)*B(N)-A(N)*B(NDATA))
      115  DC 45 I=2,NDATA
      120  J=NDATA+1-I
      125  M(I)=(D(I)-E(I)*M(I+1))/A(I)
      130  J=I
      135  I=1
      140  IF ((XIN(I)-XDATA(1)) 95, 95, 55
      145  IF ((XIN(I)-XDATA(J+1)) 70, 70, 60
      150  IF (J+1-NDATA) 65, 70, 70
      155  J=J+1
      160  GO TC 55
      165
      170
      175
      180
      185
      190
      195
      200

```

```

70   IF ((XIN(I)-XDATA(NDATA))>75,110,110
C 205
75   CX=XCDATA(J+1)-XDATA(J)
C 210
    IF (NWCT-1)=80,85,85
C 215
80   YOUT(I)=M(J)/(6.0*Dx)*(XDATA(J+1)-XIN(I))*3+M(J+1)/(6.0*Dx)*(XIN(
C 220
11)-XCDATA(J))*3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*Dx)+(XIN(
2(I)-XDATA(J))*((YDATA(J+1)/DX-M(J+1)/6.0*Dx)
C 225
IF (NWOT)=85,90,95
C 230
235
85   YPRIME(I)=(-M(J)*(XDATA(J+1)-XIN(I))*2/2.0+M(J+1)*(XIN(I)-XDATA(J
1))*2/2.0+YDATA(J+1)-YDATA(J))/DX-(M(J+1)-M(J))/6.0*Dx
C 240
90   I=I+1
C 245
95   IF ((I-NXY)=50,50,120
C 250
    YDASH=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))-((M(1)/3.0+M(2)/6.0)*
C 255
1(XDATA(2)-XDATA(1))
C 260
    IF (NWCT-1)=100,105,100
C 265
100  YOUT(I)=YDATA(1)-YDASH*(XDATA(1)-XIN(I))
C 270
    IF (NWOT)=105,90,105
C 275
105  YPRIME(I)=YDASH
C 280
    GOTO 90
C 285
110  YDASH=(YDATA(NDATA)-YDATA(N))/((XDATA(NDATA)-XDATA(N))+((M(NDATA)/3.
C 290
10+M(N)/6.0)*(XDATA(NDATA)-XDATA(N)))
C 295
115  IF (NWCT-1)=115,105,115
C 300
115  YOUT(I)=YDATA(NDATA)+YDASH*(XIN(I)-XDATA(NDATA))
C 305
115  IF (NWOT)=105,90,105
C 310
120  RETURN
C 315
C 320
C 325-
C 330

```

```

      SUBROUTINE C1 (XDATA,YDATA,NDATA,XIN,YOUT,NXY,NTYPE)
      REAL N
      DIMENSION P(15), A(15), B(15), E(15), XDATA(1), YDATA(1),
     1 YOUT(1)
      IF (NDATA-1) 5,5,15
      DO 10 I=1,NXY
      YOUT(I)=YDATA(1)
      RETURN
      IF (NDATA-2) 25,25,20
      IF (NTYPE) 90,90,25
      J=1
      I=1
      IF (XIN(I)-XDATA(2)) 65,65,35
      IF (XIN(I)-XDATA(NDATA-1)) 40,70,70
      IF (XIN(I)-XDATA(J)) 50,60,45
      IF (XIN(I)-XDATA(J+1)) 60,60,50
      J=J+1
      IF (J-NDATA) 40,55,55
      J=1
      GO TO 40
      YOUT(I)=YDATA(J)+(YEATA(J+1)-YDATA(J))/ (XEATA(J+1)-XDATA(J)) * (XIN(
     1I))-XCATA(J))
      GO TO 75
      YOUT(I)=YDATA(1)+(YEATA(2)-YDATA(1))/ (XDATA(2)-XDATA(1)) * (XIN(I))-X
     1DATA(1)
      GO TO 75
      YOUT(I)=YDATA(NDATA-1)+(YCATA(NDATA)-YDATA(NDATA-1))/ (XCATA(NDATA)
     1-XDATA(NDATA-1))*(XIN(I)-XDATA(NDATA-1))
      IF (I-NXY) 80,85,85
      I=I+1
      GO TO 30
      RETURN
      A(1)=1.0
      B(1)=0.0
      D(1)=0.0
      N=NDATA-1
      DC 95 I=2,A
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))/ (6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0

```

```

95   D(I) = (YDATA(I+1)-YDATA(I)) / (XDATA(I+1)-XDATA(I)) - (YDATA(I)-YDATA(I-1)) / (XDATA(I)-XDATA(I-1)) - (XDATA(I-1)*D(I-1)+D(I-1))/6.0/A(I-1)
     1-1) / (XDATA(I)-XDATA(I-1)) - (XDATA(I+1)-XDATA(I)) *D(I-1) + D(I-1) / 6.0/A(I-1)
     M(NDATA)=0.0
     DO 100 II=2,N
     I=NDATA+1-II
     M(I)=(D(I)-B(I))*M(I+1))/A(I)
     M(1)=0.0
     100 J=1
     I=1
     105 IF (XIN(I)-XDATA(I)) 115,130,110
     110 IF (XIN(I)-XDATA(NDATA)) 140,135,120
     115 JP=1
     KP=2
     120 GC TC 125
     JP=NCDATA
     KP=NCDATA-I
     125 YPRIPE=(YDATA(KP)-YDATA(JP)) / (XDATA(KP)-XDATA(JP))-M(KP)/6.0*(XDATA
     1A(KP)-XDATA(JP))
     YOUT(I)=YDATA(JP)+(XIN(I)-XDATA(JP))*YPRIME
     GO TO 175
     130 YOUT(I)=YDATA(I)
     GO TC 175
     135 YCUT(I)=YDATA(NDATA)
     GO TC 175
     140 IF (XIN(I)-XDATA(J)) 150,160,145
     145 IF (XIN(I)-XDATA(J+1)) 170,165,150
     150 J=J+1
     155 IF (J-NDATA) 140,155,155
     J=1
     160 GC TC 140
     YOUT(I)=YDATA(J)
     GO TC 175
     165 YOUT(I)=YDATA(J+1)
     GO TC 175
     170 DX=XDATA(J+1)-XDATA(J)
     YOUT(I)=M(J)/(6.0*Dx)*(XDATA(J+1)-XIN(I))*3+N(J+1)/(6.0*Dx)*(XIN
     J,I)-XDATA(J))*3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-N(J)/DX)+N(J)
     2(I)-XDATA(J))*((YDATA(J+1)/DX-N(J+1)/DX)/6.0*Dx)
     175 IF (I-NXY) 180,185,185
     180 I=I+1
     GO TC 105
     185 RETURN
     END

```

```

5
      SUBROUTINE EQ (IX,LCG1,X1,Y1,X2,Y2)
      REAL LINE
      DIMENSION X1(1), Y1(1), X2(1), Y2(1), LINE(121), XNUM(13)
      DATA SYMBOL/1H+/, DASH/1H-/, CROSS/1H+, BLANK/1H /
      YMIN=Y1(1)
      XMIN=X1(1)
      YMAX=YMIN
      XMAX=XMIN
      DO 5 I=1,IX
      IF (Y2(I).LT.YMIN) YMIN=Y2(I)
      IF (Y2(I).GT.YMAX) YMAX=Y2(I)
      IF (X2(I).LT.XMIN) XMIN=X2(I)
      IF (X2(I).GT.XMAX) XMAX=X2(I)
      IF (Y1(I).GT.YMAX) YMAX=Y1(I)
      IF (X1(I).GT.XMAX) XMAX=X1(I)
      CONTINUE
      IF (XMAX.EQ.XMIN.OR.YMIN.EQ.YMAX) GO TO 85
      YH=YMAX+(YMAX-YMIN)/25.0
      YL=YMIN-(YMAX-YMIN)/25.0
      XH=XMAX+(XMAX-XMIN)/38.3333
      XL=XMIN-(XMAX-XMIN)/38.3333
      IF ((YH-YL)/(XH-XL).GT.0.75) XH=1.3333*(YH-YL)+XL
      IF ((YH-YL)/(XH-XL).LT.0.75) YH=0.75*(XH-XL)+YL
      XMAX=(XMIN+XMAX-XH+XL)/2.0
      XH=XL-XL+XMAX
      XL=XMAX
      XMAX=(YMIN+YMAX-YH+YL)/2.0
      YH=YH-YL+XMAX
      YL=XMAX
      XMAX=ABS(XH)
      XMIN=ABS(XL)
      YMIN=ABS(YL)
      YMAX=ABS(YH)
      IF (XMIN.GT.XMAX) XMAX=XMIN
      IF (YMIN.GT.YMAX) YMAX=YMIN
      XMAX=ALCG1(XMAX)
      YMAX=ALCG1(YMAX)
      IF (XMAX.LT.0.0) XMAX=XMAX-1.0
      IF (YMAX.LT.0.0) YMAX=YMAX-1.0
      MX=-XMAX
      E 10
      E 15
      E 20
      E 25
      E 30
      E 35
      E 40
      E 45
      E 50
      E 55
      E 60
      E 65
      E 70
      E 75
      E 80
      E 85
      E 90
      E 95
      E 100
      E 105
      E 110
      E 115
      E 120
      E 125
      E 130
      E 135
      E 140
      E 145
      E 150
      E 155
      E 160
      E 165
      E 170
      E 175
      E 180
      E 185
      E 190
      E 195
      E 200

```

```

MY=--YMAX E 205
      WRITE (LOG1,10) MX, MY E 210
      FORMAT (20X,4EHSCALES - 'X' IS SHOWN TIMES 10 TC THE POWER OF,13,4 E 215
10H   'Y' IS SHOWN TIMES 10 TO THE POWER OF,13,/ E 220
      YINC=(YH-YL)/54.0 E 225
      YINC2=YINC/2.0 E 230
      X RANGE=XH-XL E 235
      DO 70 KLINE=1,55 E 240
      IF (KLINE.EQ.1.OR.KLINE.EC.55) GO TC 25 E 245
      DO 15 L=2,120 E 250
      LINE(L)=BLANK E 255
      IF (KLINE.EQ.7.OR.KLINE.EG.13.OR.KLINE.EQ.15.OR.KLINE.EQ.25.CR.KLI E 260
1NE.EC.31.OR.KLINE.EC.37.OR.KLINE.EQ.43.CR.KLINE.EQ.45) GC TO 20 E 265
      LINE(1)=XI E 270
      LINE(121)=XI E 275
      GO TC 40 E 280
      LINE(1)=CASH E 285
      LINE(121)=DASH E 290
      GO TC 40 E 295
      DO 30 L=2,120 E 300
      LINE(L)=DASH E 305
      LINE(1)=CRCSS E 310
      LINE(121)=CROSS E 315
      DO 35 L=11,111,10 E 320
      LINE(L)=XI E 325
      GO TC 60 E 330
      DO 50 I=1,IX E 335
      IF (Y2(I).GT.YH+YINC2.OR.Y2(I).LE.YH-YINC2) GC TO 45 E 340
      L=(X2(I)-XL)/XRANGE*120.0+1.5 E 345
      LINE(L)=SYMBOL E 350
      IF (Y1(I).GT.YH+YINC2.OR.Y1(I).LE.YH-YINC2) GC TO 50 E 355
      L=(X1(I)-XL)/XRANGE*120.0+1.5 E 360
      LINE(L)=SYMBOL E 365
      CONTINUE E 370
      IF (KLINE.EQ.1.OR.KLINE.EG.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLIN E 375
1E.EQ.25.OR.KLINE.EQ.31.CR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.4 E 380
29.OR.KLINE.EQ.55) GC TC 60 E 385
      WRITE (LOG1,55) LINE E 390
      FORMAT (8X,121A1) E 395
      GO TC 70 E 400

```

```

60      YNUM=YH*10.0**HY
       WRITE (LOG1,65) YNUM,LINE
65      FORMAT (1X,F6.3,1X,121A1)
70      YH=YH-YINC
     XNUM(1)=XL*10.0**HX
     XINC=((XH-XL)/12.0)*10.0**HX
    DO 75 I=2,13
     XNUM(I)=XNUM(I-1)+XINC
     WRITE (LCG1,80) XNUM
75      FORMAT (6X,12(F6.3,4X),F6.3)
     RETURN
85      WRITE (LCG1,90)
     FORMAT (//,35X,54HNC PLCT HAS BEEN MADE BECAUSE 'X' CR 'Y' RANGE I
1S ZERO)
     RETURN
90      END

```

E 405  
E 410  
E 415  
E 420  
E 425  
E 430  
E 435  
E 440  
E 445  
E 450  
E 455  
E 460  
E 465  
E 470  
E 475  
E 480-

```

5          10
      15
      20
      25
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      165
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      175
      180
      185
      190
      195
      200

SUBROUTINE FQ (ISTAK,PLTSZE,ITRIG,TITLE,IKCUM,IFPLOT)
DIMENSION TITLE(8)
IF (ITRIG.EQ.2.AND.IFPLCT.NE.2) CALL FLCT (PLTSZE,0.,-3)
PLTIT=PLTSZE*.1
IF (ISTAK.LT.2) GO TO 5
BAL=.35*PLTSZE
XLEN1=.3*PLTSZE
XLEN2=XLEN1
YLEN1=.25*PLTSZE
YLEN2=.1.*YLEN1
XBACK1=-1.9
XBACK2=-6.2
GO TO 25
5     IF (ISTAK.EQ.0) GO TO 10
XLEN1=.70*PLTSZE
XLEN2=.15*PLTSZE
XBACK1=-1.9-.20*PLTSZE
XBACK2=-6.2-.20*PLTSZE
IF (IKCUM.EQ.0) GO TO 15
GO TO 20
CONTINUE
10    XLEN1=.15*PLTSZE
XLEN2=.70*PLTSZE
XBACK1=-1.9+.20*PLTSZE
XBACK2=-6.2+.20*PLTSZE
IF (IKCUM.EQ.0) GO TO 20
BAL=.25*PLTSZE
YLEN1=.50*PLTSZE
YLEN2=-.15*PLTSZE
GO TO 25
BAL=.50*PLTSZE
YLEN1=.15*PLTSZE
YLEN2=-.50*PLTSZE
CONTINUE
15    YBACK1=-(.35+BAL)
YBACK2=YBACK1-.01*PLTSZE-.175
CALL PLOT (0.0,-PLTSZE,-3)
CALL FLCT (7.0,FLTTIT,-3)
CALL PLCT (0.0,BAL,3)
CALL FLCT (XLEN1,BAL,-2)

```

```
CALL FLCT (XLEN2, 0.0, 2)
CALL PLCT (0.0, YLEN1, 3)
CALL FLCT (0.0, YLEN2, 2)
GO TO (30, 35), ITRIG
CALL SYMBOL (XBACK1, YBACK1, .175, 22HSTREAMSURFACE SECTIONS, 0.0, 22)
30 GO TO 40
35 XBACK1=XBACK1+.35
CALL SYMBOL (XBACK1, YBACK1, .175, 18HCARTESIAN SECTIONS, 0.0, 18)
CALL SYMBOL (XBACK2, YBACK2, .175, TITLE, 0.0, 72)
40 RETURN
END
```

#### 4. PROGRAM LOGIC

The calculation procedure which has been described in this report is performed primarily in the main program and Subroutine BQ. The calculations regarding the construction of the camber line, the stacking of the streamsurface blade sections, and the determination of manufacturing sections are performed in the main program. Subroutine BQ applies the thickness distribution to the camber line and determines quantities necessary to obtain the Cartesian coordinates of the section from the streamsurface coordinates. Subroutine DL is the curve-fitting routine, and CQ is used to determine slopes of various spline curves at particular points. EQ produces the line-printer section plot in the printed portion of the output, and FQ produces axes on the section plots for IFPLOT = 1, 2, or 3.

A description of the calculation procedure employed in the main program and in Subroutine BQ is described below. Each step is keyed to its location in the program by the parenthetical deck serialization.

1. The input data is read and printed. (A155-A680)
2. If precision plotting is specified, the plot is initialized, and axes produced if IFPLOT = 1 or 3. (A695-A710)
3. A loop which creates a section on each streamsurface is commenced. (A715)
4. The axial locations of the intersections of a particular streamsurface with the computing stations describing the blade are determined. The meridional streamsurface length is obtained as described in Equation (1). (A720-A780)
5. The parameters relating to the streamsurface blade section are interpolated (or extrapolated) from the input tables. If NSPEC = 1, they are taken to be radially uniform. If NSPEC = 2, linear interpolation is used; if NSPEC = 3, spline-curve interpolation is employed. (A785-A840)
6. The loop to determine the optimal camber line is initiated. (A855)
7. The first estimate of true chord is calculated per Equation (2), and the solidity as in Equation (3). (A870-A910)
8. The incidence angle and extra deviation applicable to the particular section are obtained by interpolation of the radius at the leading edge of the streamsurface in the input tables. (A915-A920)

9. The section angle at the leading edge is determined as in Equation (6). (A925)
10. The quantities required for the deviation angle calculation are obtained by interpolation from various figures of Reference 2. (A935-A960)
11. The deviation angle is calculated using Equation (5). (A995-A1000)
12. The section angle at the trailing edge is calculated using Equation (7), and at internal points using Equation (8), with fractions of deviation obtained by radial interpolation from the input distributions based on the streamsurface radius at the trailing edge of the blade. (A1020-A1085)
13. A camber line is constructed of cubic segments following the analysis of Equations (9) - (15) for the initial value of  $S/R_o$ . The number of inflection points is determined. (A1090-A1350)
14. The iteration on solidity is performed until the tolerance is within the prescribed limit. (A1355-A1395)
15. Steps 13 and 14 are repeated for IPASS-1 values of the  $S/R_o$  parameter. (A1406-A1450)
16. The range of  $S/R_o$  with the minimum number of inflection points is established. (A1480-A1600)
17. Steps 13, 14 and 15 are repeated for finer increments of the  $S/R_o$  parameter in the range determined in 16. The maximum value of the minimum radius of curvature in this range is determined. (A1645-A1690)
18. Still finer increments of  $S/R_o$  on either side of the  $S/R_o$  value which produced the maximum value of the minimum radius of curvature in 17 are examined to find the optimal  $S/R_o$  value. (A1730-A1745)
19. The details of the optimal camber line are printed if IPRINT = 0 or 1. (A1755-A1810)
20. The normalized chord length of the optimal camber line is computed. (A1820)
21. The total streamsurface length is calculated. (A1830-A1890)
22. If IPRINT = 0 or 1, the parameters defining the section are printed. (B65-B115)

23. The coefficients of the two thickness equations are computed. (B175-B220)
24. At each point of the camber line, the corresponding coordinates on each blade surface are obtained from the coordinates and slope of the camber line, and the appropriate thickness, scaled for an overall section meridional chord of unity. (B225-B310)
25. The section area and centroid location are determined. (B315-B365)
26. The camber line is redefined in terms of 100 points to assure sufficient points for accurate linear interpolation in the determination of  $\Phi$  (Figure 1), needed for the eventual Cartesian coordinate determination. (B380-B440)
27. The various streamsurface section properties are determined. (B445-B560)
28. If IPRINT = 0 or 1, details of the normalized blade section and a line-printer plot are produced. (B575-B750)
29. Sectional properties are scaled to produce the "dimensional" results. (B755-B830)
30. If IPRINT = 0 or 1, the section information is printed. (B840-B1095)
31. The coordinates of 31 points describing the leading edge are determined. (B1070-B1080)
32. The origin of the coordinate system is shifted to the stack axis, and the relative  $\Phi$  values for the blade surfaces are determined. (B1120-B1595)
33. If IFPLOT = 1 or 3, the streamsurface section plot is produced. (A1950-A2040)
34. If the calculations for aerodynamic analysis are required, various items related to the camber line are stored. (A2045-A2095)
35. The Cartesian coordinates for each point on the section surface are computed, and printed if IPRINT = 0 or 1. (A2100-A2435)
36. The loop initiated in 3 is repeated for each streamsurface. (A2440)
37. Unless IPRINT = 1, the volume of the blade is computed and printed. (A2445-A2555)

38. If specified, the calculations for aerodynamic analysis are performed and printed, and punched if IPUNCH = 1. (A2560-A2790)
39. If IFPLCT = 2 or 3, the axes are drawn and titled for the superimposed plot of the manufacturing sections. (A2800)
40. If no output relating to manufacturing sections is specified by either IFPLOT or IPRINT, the remainder of the program is bypassed. Alternatively, if printed details of the manufacturing sections are specified, a heading is printed. (A2805-A2835)
41. The location of each of the manufacturing planes is determined. (A2840-A2865)
42. The (Cartesian) coordinates of each point on the blade surface are obtained by spline-curve interpolation at each of the manufacturing sections. (A2870-A2945)
43. A loop that is performed for each manufacturing section is initiated. This loop contains the determination of section properties and the output of results for the section. If IPRINT = 0 or 2, section properties and coordinates are printed. (A2950-A3495)
44. If IFPLOT = 2 or 3, a plot of the manufacturing sections is produced. (A3510-A3605)
45. If IFPLOT = 4, an individual plot of the manufacturing sections is made. The axes are rotated clockwise until the chord line is horizontal. The angle of rotation is indicated as the stagger angle. (A3610-A3845)
46. The loop initiated in Step 43 for each manufacturing section is terminated. (A3850)
47. If precision plots have been made, the plotting is terminated. (A3855)

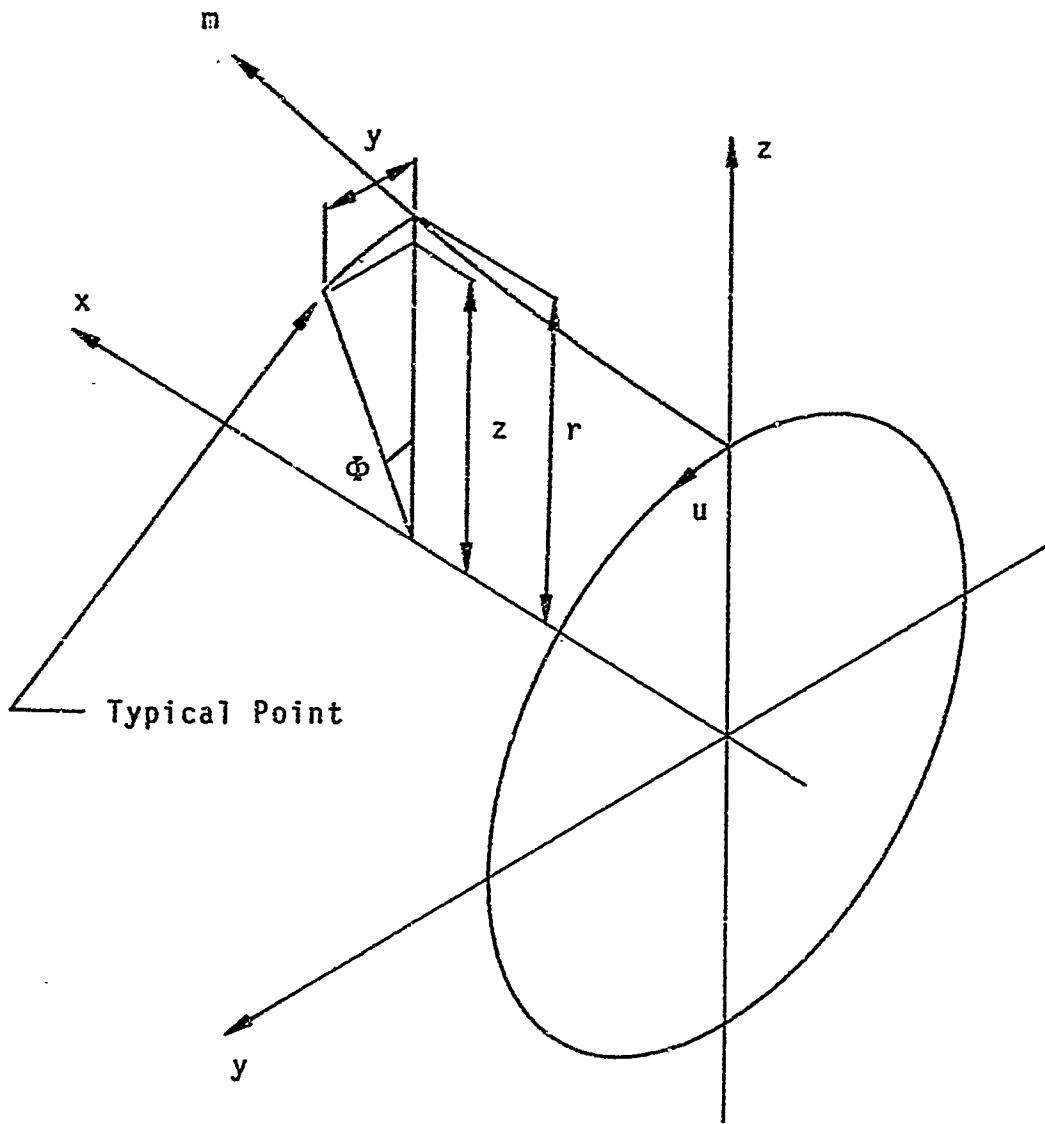


Figure 1. Cartesian and Streamsurface  
Coordinates of a Point

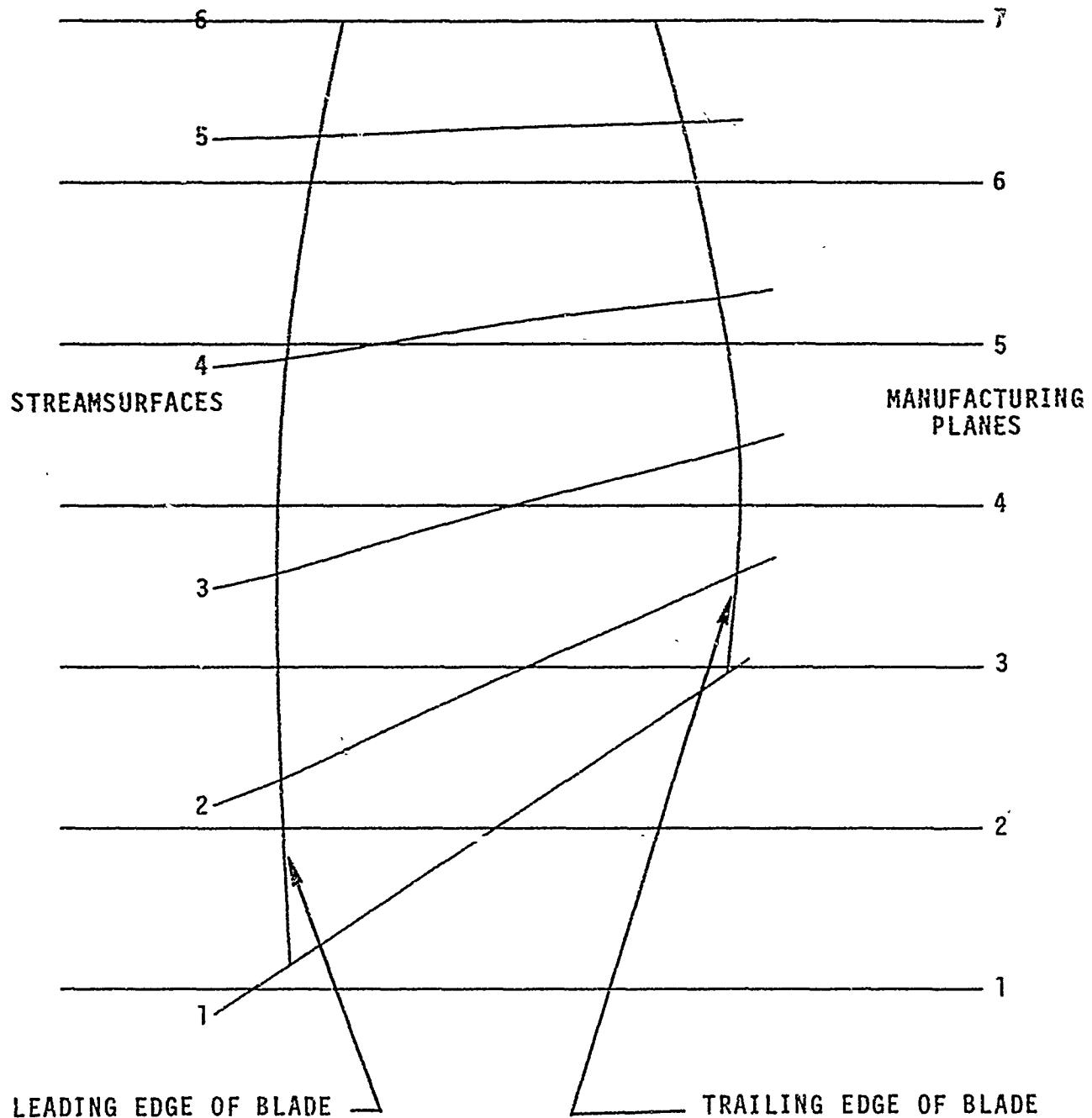


Figure 2. Locations of Streamsurfaces and Manufacturing Planes for Example Blade Design

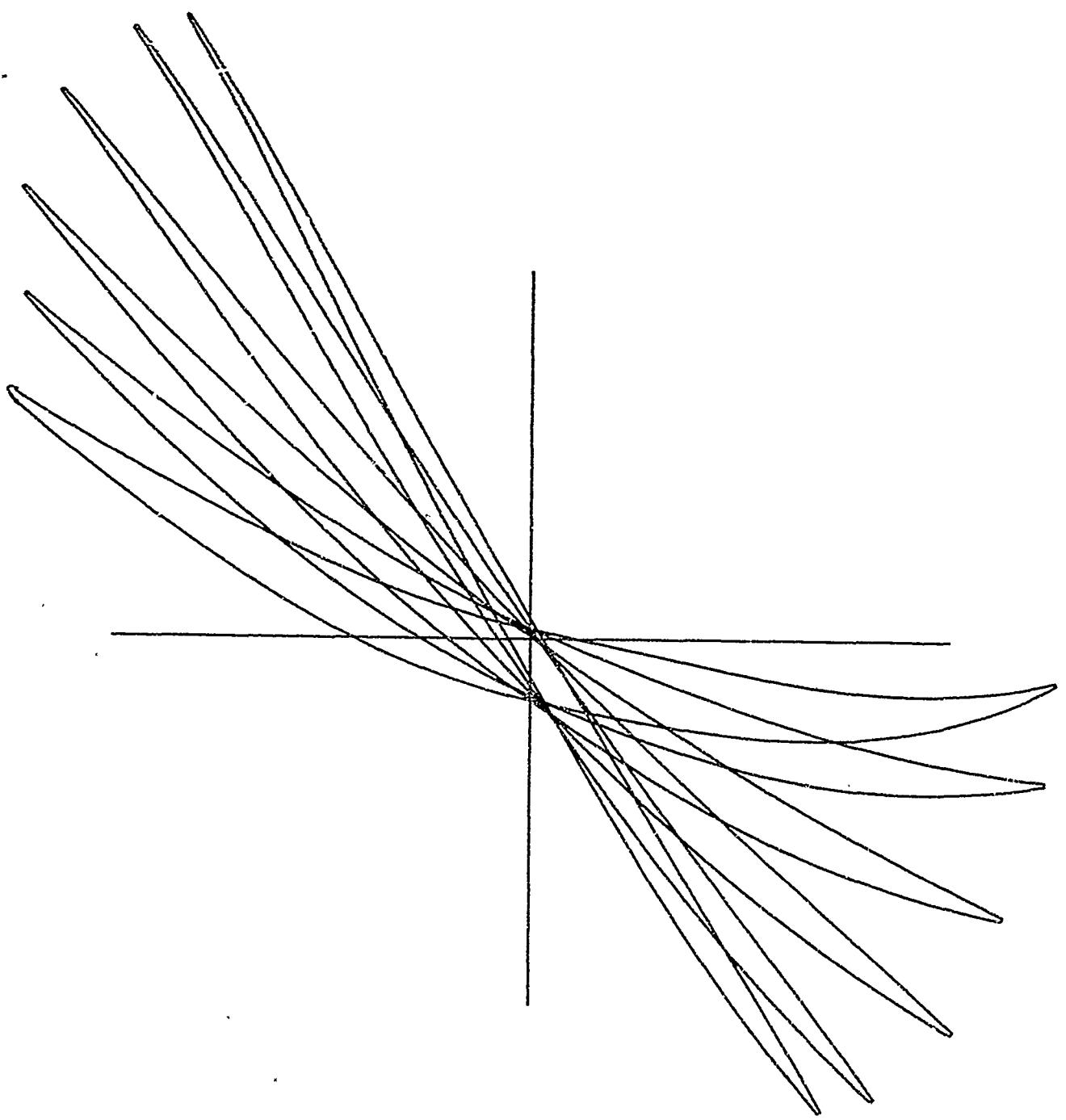


Figure 3, Example Blade Design:  
Streamsurface Sections

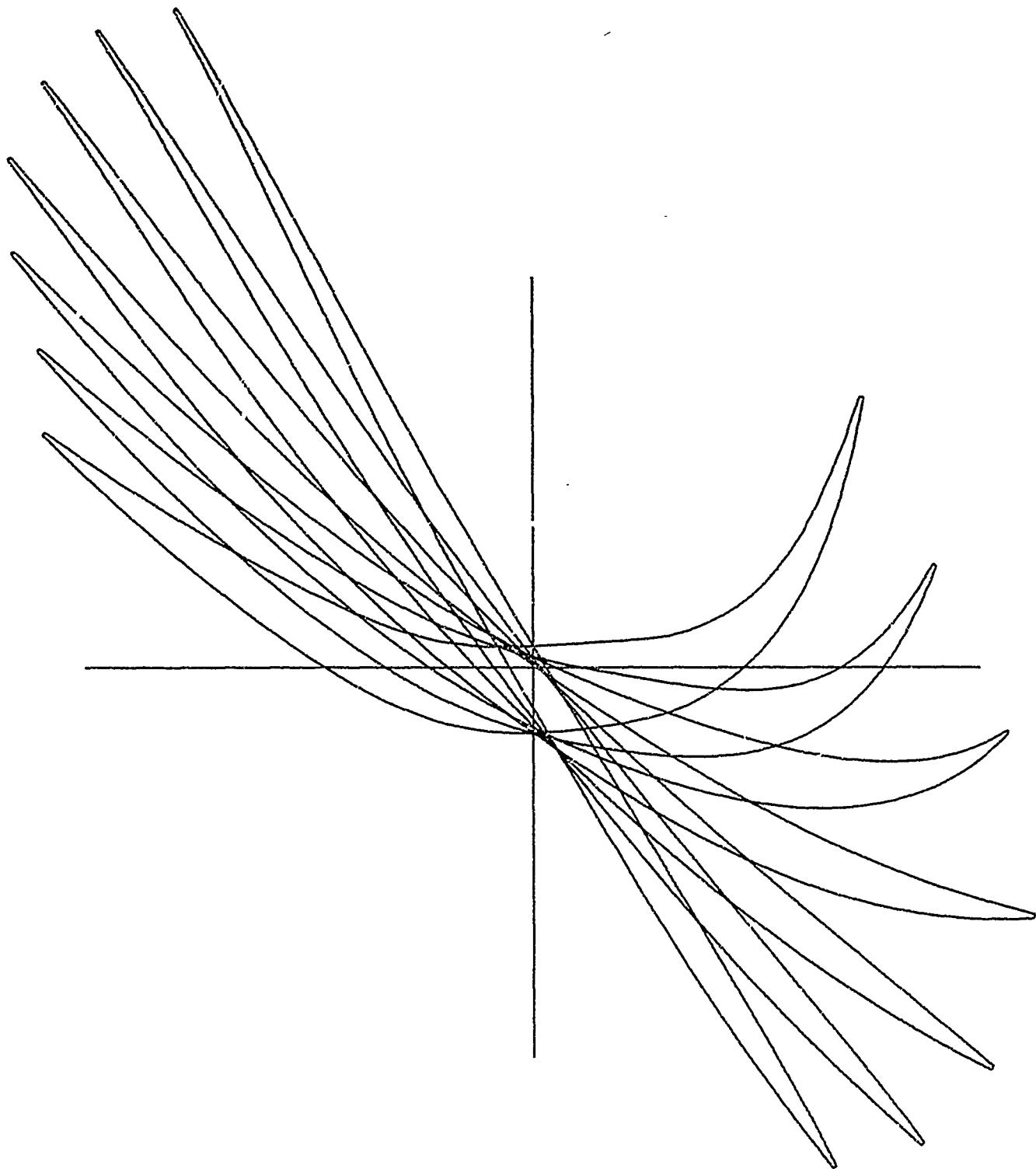


Figure 4. Example Blade Design:  
Cartesian Sections

## REFERENCES

1. Frost, G.R., Hearsey, R.M., and Wennerstrom, A.J., "A Computer Program for the Specification of Axial Compressor Airfoils," Aerospace Research Laboratories, Wright-Patterson AFB, Ohio, ARL 72-0171, AD 756879, December 1972.
2. Johnsen, I.A., Bullock, R.O., et al, "Aerodynamic Design of Axial Flow Compressors," Lewis Research Center, Cleveland, Ohio, NASA SP-36, 1965.